Nutrients and Phytoplankton in Prince Edward Island Inlets during Late Summer to Fall: 2001 – 2003

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CONTENTS

ABSTRACT ix

RÉSUMÉ xi

INTRODUCTION 1

MATERIALS AND METHODS 5
Sampling Program 5
Nutrient Analysis 8
Phytoplankton Analysis 9
Scanning Electron Microscopy 10
Statistics 11

RESULTS 13
Nutrients 13
Phytoplankton 23

DISCUSSION 40
Nutrient Limitation 40
Nutrient-Phytoplankton Relationships 50
Phytoplankton 58

CONCLUSIONS 67

ACKNOWLEDGEMENTS 68

REFERENCES 69

APPENDICES 80

LIST OF TABLES

Table 1. Sampling locations on Prince Edward Island 6

Table 2. Precisions (%) and detection limits (μM) for the nutrient analyses 9

Table 3. Categories used for counting *Pseudo-nitzschia* spp. by light microscopy 10

Table 4. Significant differences between pairs of inlets on the basis of nutrient levels 16

Table 5. Significant differences between sampling years on the basis of nutrient levels 17

Table 6. Total cell counts, averaged over the number of sampling times (mean ± sd), for the four inlets studied in detail, for each of the years 2001–2003. 23

Table 7. Groups of phytoplankton identified for all PEI inlets sampled during the late summer and fall of 2001–2003 25

Table 8. Phytoplankton species with total cell concentrations > 100,000 cells L^{-1} (summed over all inlets in all years), for all PEI inlets sampled 27

Table 9. Morphometrics of *Pseudo-nitzschia* species identified from PEI inlets 27

Table 10. Proportion of *Pseudo-nitzschia* species at selected inlets and dates, as determined by scanning electron microscopy 34

Table 11. Similarities of phytoplankton communities within the same nutrient cluster and between different nutrient clusters. 52

Table 12. Significant Spearman correlations ($p < 0.05$) between nutrients and measures of phytoplankton abundance 54

Table 13. Principal component analysis of nutrients and 13 dominant species of phytoplankton (those species with at least one count > 100,000 cells L^{-1}). 57

Table 14. Harmful and toxic phytoplankton species identified in PEI inlets during 2001–2002, and their potential or actual affects on human health other marine biota 61

Table 15. Phytoplankton species found in our study (from Table 7), but apparently not reported elsewhere in the literature, for the Gulf of St. Lawrence 66

LIST OF FIGURES

Fig. 1. Phytoplankton and nutrient sampling locations on Prince Edward Island (PEI); fall of 2001–2003 5

Fig. 2. Phytoplankton and nutrient sampling dates in each of the PEI inlets 7

Fig. 3. Dates of nutrient sample collection for the three years of the sampling program 8

Fig. 4. Distribution of inorganic nitrogen concentrations in PEI inlets 13

Fig. 5. Distribution of total inorganic nitrogen (TIN), silicate and phosphate concentrations (in µM) in PEI inlets 14

Fig. 6. Nitrate concentrations in four inlets 18

Fig. 7. Ammonia concentrations in four inlets 20

Fig. 8. Silicate concentrations in four inlets 21

Fig. 9. Phosphate concentrations in four inlets 22

Fig. 10. Light micrographs of formalin-acetic-acid-preserved phytoplankton from PEI 28

Fig. 11. SEMs of the inside valves of *Pseudo-nitzschia* spp. from Cardigan River, PEI 29

Fig. 12. SEMs of the inside valves of *Pseudo-nitzschia* spp. from Lennox Channel (Malpeque Bay), PEI 30

Fig. 13. SEMs of the inside valves of *Pseudo-nitzschia fraudulenta* from New London Bay, PEI; 3-Dec-01 31

Fig. 14. SEM transmitted electron detector (TED) micrograph of *Pseudo-nitzschia calliantha* from Brudenell River, Prince Edward Island; 5-Nov-01 32

Fig. 15. Concentrations of the centric diatom *Skeletonema costatum* in four inlets of PEI, during the late summer and fall of 2001–2003 35

Fig. 16. Concentrations of the non-toxic pennate diatom *Pseudo-nitzschia calliantha* in four inlets of PEI, during the late summer and fall of 2001–2003 36

Fig. 17. Concentrations of the non-toxic pennate diatom *Pseudo-nitzschia delicatissima* in four inlets of PEI, during the late summer and fall of 2001–2003 37

Fig. 18. Concentrations of the non-toxic *Pseudo-nitzschia pungens* plus the toxic *P. multiseries* in four inlets of PEI, during the late summer and fall of 2001–2003 38

Fig. 19. Concentrations of the potentially toxic dinoflagellate *Karenia mikimotoi* in four inlets of PEI, during the late summer and fall of 2001–2003.....39

Fig. 20. Nutrient limitation in Cardigan River, PEI.....43

Fig. 21. Nutrient limitation in Lennox Channel, PEI.....45

Fig. 22. Nutrient limitation in New London Bay, PEI.....46

Fig. 23. Nutrient limitation in Tracadie Bay, PEI.....47

Fig. 24. Nutrient limitation in Rustico Bay, PEI.....48

Fig. 25. Distribution of diatom growth attenuation factors ([X] / ([X] + K_X)) for each nutrient and the total attenuation factor (TA, see text).....49

Fig. 26. Hierarchical cluster analysis of nutrient data 51

Fig. 27. Abundance of picoplankton and large nanophytoplankton in Tracadie Bay compared to the Bedford Basin, Scotian Shelf, and Labrador Sea. Unpublished graph courtesy of Bill Li (DFO, Dartmouth, NS).....59

LIST OF APPENDICES

Appendix A. Prince Edward Island sampling sites for water used for nutrient and phytoplankton analyses 80

Appendix A1. Boughton River sampling site 81
Appendix A2. Brudenell River sampling site 81
Appendix A3. Cardigan River sampling site 82
Appendix A4. Covehead Bay sampling site 82
Appendix A5. Darnley Basin sampling site 83
Appendix A6. Lennox Channel (Malpeque Bay) sampling site 83
Appendix A7. March Water (Malpeque Bay) sampling site 84
Appendix A8. Murray River sampling site 84
Appendix A9. New London Bay sampling site 85
Appendix A10. Rustico Bay sampling site 85
Appendix A11. Savage Harbour sampling site 86
Appendix A12. St. Marys Bay sampling site 86
Appendix A13. St. Peters Bay sampling site 87
Appendix A14. Tracadie Bay sampling site 87

Appendix B. Nutrient data, all inlets and years 88

Appendix C. Nutrient statistics, by inlet 97

Appendix C1. Nitrate statistics, by inlet 97
Appendix C2. Ammonia statistics, by inlet 97
Appendix C3. Nitrite statistics, by inlet 98
Appendix C4. TIN (NO_3 + NO_2 +NH_3) statistics, by inlet 98
Appendix C5. Silicate statistics, by inlet 99
Appendix C6. Phosphate statistics, by inlet 99

Appendices D-F. Phytoplankton cell numbers (cells L^{-1}), in all Prince Edward Island inlets studied, 2001–2003 100

Appendix D1. Phytoplankton cell numbers (cells L^{-1}), in Cardigan River, 2001 101
Appendix D2. Phytoplankton cell numbers (cells L^{-1}), in Tracadie Bay, 2001 103
Appendix D3. Phytoplankton cell numbers (cells L^{-1}), in New London Bay, 2001 105
Appendix D4. Phytoplankton cell numbers (cells L^{-1}), in Lennox Channel (Malpeque Bay), 2001 107
Appendix D5. Phytoplankton cell numbers (cells L^{-1}), in March Water (Malpeque Bay), 2001 109
Appendix D6. Phytoplankton cell numbers (cells L^{-1}), in other inlets, 2001; 1= present; 2=common 110
Appendix E1. Phytoplankton cell numbers (cells L^{-1}), in Cardigan River, 2002 111
Appendix E2. Phytoplankton cell numbers (cells L^{-1}), in Tracadie Bay, 2002 114

Appendix E3. Phytoplankton cell numbers (cells L^{-1}), in New London Bay, 2002 116
Appendix E4. Phytoplankton cell numbers (cells L^{-1}), in Lennox Channel (Malpeque Bay), 2002 119
Appendix E5. Phytoplankton cell numbers (cells L^{-1}), in Murray River, 2002 121
Appendix E6. Phytoplankton cell numbers (cells L^{-1}), in other inlets, 2002 123
Appendix F1. Phytoplankton cell numbers (cells L^{-1}), in Cardigan River, 2003 125
Appendix F2. Phytoplankton cell numbers (cells L^{-1}), in Tracadie Bay, 2003 128
Appendix F3. Phytoplankton cell numbers (cells L^{-1}), New London Bay, 2003 130
Appendix F4. Phytoplankton cell numbers (cells L^{-1}), Lennox Channel (Malpeque Bay), 2003 133
Appendix F5. Phytoplankton cell numbers (cells L^{-1}), other inlets, 2003 135

ABSTRACT

Bates, S.S. and P.M. Strain. 2006. Nutrients and phytoplankton in Prince Edward Island inlets during late summer to fall: 2001–2003. Can. Tech. Rep. Fish. Aquat. Sci. 2668: xii + 136 p.

Inlets of Prince Edward Island (PEI) provide an important source of income, offered by the rapidly growing molluscan shellfish (mostly blue mussels, *Mytilus edulis*) aquaculture industry. At the same time, some of those inlets have been described as being subject to eutrophication. Nutrient enrichment may be an advantage to the aquaculture industry by stimulating the growth of phytoplankton eaten by aquacultured mussels. However, this may occur only if nutrient concentrations are at levels that may limit phytoplankton biomass and other factors are not limiting. As well, the concentrations and ratios of nutrients may select for certain groups of phytoplankton, not all of which may be desirable food for mussels, and some of which are harmful or toxic, producing harmful algal blooms (HABs).

This study was carried out to compare the results of nutrient and phytoplankton measurements in PEI inlets, in order to look for relationships between species composition and nutrient levels. We also considered the likelihood of nutrient limitation within the phytoplankton community by comparing ambient nutrient concentrations with the inherent ability of the phytoplankton to take up the nutrients at low concentrations.

Samples for nutrients and phytoplankton were collected from 14 PEI inlets, in the late summer and fall of 2001, 2002 and 2003. Detailed time-series phytoplankton community composition and species enumeration data were obtained every week from four inlets (Cardigan River, Tracadie Bay, New London Bay, and Lennox Channel).

The inorganic nitrogen (N) in the 14 inlets was dominated by ammonia in the late summer and fall: the mean ammonia concentration (2.23 μM) was ~3.5 times higher than that of nitrate (0.64 μM) and ~19 times greater than that of nitrite (0.12 μM). The mean total inorganic N was only 3.22 μM, a value well below that thought to indicate eutrophication. Silicate (Si) and phosphate (P) levels were also low most of the time, with mean values of 1.20 and 0.45 μM, respectively. Except for P, these concentrations were generally below those believed to limit phytoplankton nutrient uptake or growth rates. Nutrient conditions in which two or three nutrients are simultaneously at limiting levels occur frequently in the fall in PEI inlets. Such "nutrient co-limitation" has not been considered extensively in the marine phytoplankton literature, but was explored here using an interactive model for multiple nutrient limitation of diatoms. Nutrient limitation of carrying capacity, determined from Redfield ratios, was also evaluated for both Bacillariophyceae (diatoms) and Dinophyceae (dinoflagellates). Both diatom growth and carrying capacity were limited by Si in about ~75% of the samples; dinoflagellate carrying capacity was limited by N in 72% of the samples and by P in 26% of the samples. Comparisons among the different inlets show that limitation varies, both between inlets in the same year and between years in the same inlet. Several multivariate statistical analyses identified relationships between the phytoplankton and nutrient levels. However, it was difficult

to find clear-cut relationships that might help define the specific nutrient conditions that select for individual phytoplankton species or groups.

Of the 124 distinct species of phytoplankton identified for all inlets studied during 2001-2003, there were 49 centric diatoms (Bacillariophyceae), 27 pennate diatoms (Bacillariophyceae), 36 dinoflagellates (Dinophyceae), 3 Dictyochophyceae, 2 Chlorophyceae, 2 Cyanophyceae, 1 Haptophyceae, 1 Chrysophyceae, 1 Euglenophyceae, 1 Litostomatoea, and 1 protist. Of these, 11 have apparently never before been reported in the Gulf of St. Lawrence. The diatom *Skeletonema costatum* was the most abundant species. Nineteen potentially toxic or harmful species were recorded, but their numbers were generally too low to have caused any shellfish harvesting closures or environmental harm during the sampling period. The toxic dinoflagellate *Karenia mikimotoi* was abundant in Cardigan River during October 2001 and 2003, but no harmful effects were observed. The domoic-acid-producing diatom *Pseudo-nitzschia multiseries* was infrequently found, and only in low numbers. Other species of *Pseudo-nitzschia*, including the non-toxic *P. calliantha*, *P. pungens*, and *P. delicatissima*, bloomed in its place. Two new species of *Pseudo-nitzschia* (*P. americana* and the tentatively identified *P. subpacifica*) were reported for the first time in the Gulf of St. Lawrence. *Pseudo-nitzschia fraudulenta* was identified for the first time in PEI inlets.

During all three years, Tracadie Bay exhibited an order of magnitude lower number of total phytoplankton cells than did Cardigan River; Lennox Channel and New London Bay showed intermediate values. More data are required to explain this finding, but we calculated that Tracadie Bay had a greater percentage of harvesting lease area coverage (37%) than did Cardigan River (20%). This study points out the importance of continuing to compile phytoplankton species lists over time, in order to look for species that are toxic / harmful or that have never before appeared in our waters, as well as to better understand the dynamics of phytoplankton blooms.

RÉSUMÉ

Bates, S.S. and P.M. Strain. 2006. Nutrients and phytoplankton in Prince Edward Island inlets during late summer to fall: 2001–2003. Can. Tech. Rep. Fish. Aquat. Sci. 2668: xii + 136 p.

Les eaux côtières protégées de l'Île-du-Prince-Édouard (I.-P.-E.) abritent une industrie conchylicole en pleine croissance (basée sur la moule bleue, *Mytilus edulis*) qui fournit d'importants revenus à l'économie. Cependant certaines de ces baies et estuaires ont été identifiées comme étant sujettes à l'eutrophisation. L'enrichissement en éléments nutritifs recèle des avantages possibles pour l'aquaculture s'il favorise la croissance du phytoplancton dont se nourrit la moule cultivée. Cependant de tels avantages seront réalisés seulement si la concentration en éléments nutritifs agit aussi comme facteur limitant de la biomasse du phytoplancton, et que d'autres facteurs limitant le phytoplancton n'entrent pas en jeu. En outre, les concentrations absolues et relatives d'éléments nutritifs dissoutes peuvent favoriser certaines formes de phytoplanctons par rapport à d'autres, y compris des espèces indésirables comme nourriture pour la moule et certaines espèces nuisibles ou toxiques, qui pourraient mener éventuellement à des blooms algaux nuisibles.

La présente étude a utilisé les résultats du dosage d'éléments nutritifs et d'énumérations du phytoplancton dans certaines eaux protégées de l'I.-P.-E., dans le but d'identifier des rapports entre la concentration en éléments nutritifs et la composition spécifique du phytoplancton. Nous avons aussi considéré la possibilité d'une limitation du phytoplancton par la disponibilité d'éléments nutritifs, en comparant les concentrations ambiantes d'éléments nutritifs avec la capacité inhérente du phytoplancton d'absorber les éléments nutritifs à de basses concentrations.

Des échantillons d'eau de mer et de phytoplancton ont été prélevés dans 14 estuaires de l'I.-P.-É. tard en été et pendant l'automne en 2001, 2002 et 2003. Des séries hebdomadaires détaillées d'énumérations pour déterminer la composition spécifique du phytoplancton furent effectuées pour quatre localités, soit Cardigan River, Tracadie Bay, New London Bay et Lennox Channel.

L'azote inorganique dissoute (N) dans les 14 estuaires était dominée par les sels d'ammonium vers la fin de l'été et en automne : la concentration moyenne en ammonium (2.23 µM) était environ 3.5 fois supérieure à celles des nitrates (0.64 µM) et environ 19 fois supérieure à celles des nitrites (0.118 µM). La concentration globale moyenne en azote inorganique (3.22 µM) fut de beaucoup inférieure à la concentration présumée indicatrice de l'eutrophisation. Les concentrations en silice (Si) et en phosphate (P) ont été basses aussi, avec des valeurs moyennes de 1.20 µM et de 0.45 µM, respectivement. En général, à l'exception du P, ces concentrations étaient inférieures à celles présumées limitatrices pour la nutrition et la croissance du phytoplancton. Il arrive fréquemment en automne que deux ou trois éléments se trouvent simultanément à des niveaux limitants pour le phytoplancton. De telles situations de « co-limitation nutritionnel » n'ont pas été étudiées en détail dans la littérature sur le phytoplancton marin, mais le phénomène est exploré ici à l'aide d'un modèle interactif pour les limitations multiples de la nutrition des diatomées. Les limitations nutritionnels de la biomasse, déterminées

d'après les rapports Redfield, ont aussi été évaluées pour les diatomées et les dinoflagellés. La croissance et la capacité en biomasse des diatomées étaient limitées par le Si dans environ 75% des échantillons; la capacité en biomasse des dinoflagellés était limitée par le N dans 72% des échantillons et par le P dans 26%. Les comparaisons parmi les estuaires indiquent que la limitation peut varier d'un estuaire à l'autre au cours d'une année donnée, ainsi que dans un même estuaire d'une année à l'autre. Un certain nombre d'analyses statistiques à multiples variables ont démontré des rapports entre le phytoplancton et les concentrations en éléments nutritifs. Par contre il a été difficile d'identifier des rapports nets qui permettraient une définition de conditions sélectives pour des espèces ou pour des groupes de phytoplanctons.

Parmi les 124 espèces de phytoplancton identifiées dans l'étude, il y avait 49 espèces de Bacillariophyceae centriques; 27 de Bacillariophyceae pennées; 36 de Dinophyceae; 3 de Dictyochophyceae; 2 de Chlorophyceae; 2 de Cyanophyceae; 1 de Haptophyceae; 1 de Chrysophyceae; 1 de Euglenophyceae; 1 de Litostomatoea; et 1 protiste. Parmi toutes ces espèces il semblerait que 11 n'aient jamais été recensées dans le Golfe du Saint-Laurent auparavant. La diatomée *Skeletonema costatum* fut l'espèce la plus abondante. Dix-neuf espèces possiblement toxiques ou nuisibles furent recensées, mais de façon générale leurs nombres étaient trop bas pour nuire à la pêche ou à la conchyliculture, ou encore à l'environnement, pendant la période d'échantillonnage. Le dinoflagellé toxique *Karenia mikimotoi* était abondant dans la Cardigan River en octobre 2001 et 2003, mais aucun effet nuisible n'a été observé. La diatomée *Pseudo-nitzschia multiseries*, qui produit l'acide domoïque, fut rarement recensée et en petits nombres seulement. D'autres espèces de *Pseudo-nitzschia*, notamment les espèces non-toxiques *P. calliantha*, *P. pungens*, et *P. delicatissima*, ont poussé à sa place. Deux nouvelles espèces de *Pseudo-nitzschia* (*P. americana* et possiblement *P. subpacifica*) furent recensées pour la première fois dans le Golfe du Saint-Laurent. Le *Pseudo-nitzschia fraudulenta* fut trouvé pour la première fois dans les eaux de l'I.-P.-É.

Au cours des trois saisons d'échantillonnage la Tracadie Bay a démontré une densité cellulaire du phytoplancton inférieure à celle de Cardigan River par un plein ordre de magnitude; Lennox Channel et New London Bay avaient des densités intermédiaires. Davantage de données seraient nécessaires pour expliquer un tel résultat, mais nous avons calculé que Tracadie Bay avait un plus grand pourcentage de sa surface occupée par les activités conchylicoles (37%) comparativement à Cardigan River (20%). Cette étude démontre l'importance du recensement continu des espèces du phytoplancton, afin d'identifier les espèces toxiques / nuisibles, les espèces nouvelles dans nos eaux, et de mieux comprendre les dynamiques du phytoplancton.

INTRODUCTION

Coastal inlets receive nutrient inputs from the land (via rivers and non-point sources), the benthos (via nutrient regeneration), the atmosphere, and offshore waters (Jickells 1998; Pinckney *et al.* 2001; Paerl 2006). The concentration and relative abundance of these nutrients are among the many factors that influence the dynamics of phytoplankton blooms and the particular phytoplankton species that occur within the inlets. Excess nutrients may lead to eutrophication, resulting in increased photosynthetic biomass and production, although the linkages are often non-linear and complex (Cloern 2001). This can be advantageous for filter-feeding bivalves, such as aquacultured mussels and oysters, if the phytoplankton species are of the proper size and nutritional quality. However, the nutrient stimulation of biomass may also lead to toxic or otherwise harmful phytoplankton species that result in harmful algal blooms (HABs) (Smayda 1989, 1990, 2006; Burkholder 1998). Toxic blooms contaminate molluscan shellfish with phycotoxins (= biotoxins), resulting in the closure of shellfish harvesting, loss of income to aquaculturists, and sickness or death of humans who consume contaminated product that may have gone undetected (Anderson 1989; Hallegraeff 2003; Glibert *et al.* 2005).

According to Liebig's law of the minimum, the yield of any organism is limited by the factor present in the lowest amount in relation to its requirements (de Baar 1994). Other than light and nutrient limitation, other factors that control phytoplankton biomass include grazing, sinking, advection, allelopathy, viruses, bacteria, and parasitic fungi (e.g. Friedrichs and Hofmann 2001; Irigoien *et al.* 2002; Huisman *et al.* 2004; Sarthou *et al.* 2005). In the case of nutrients, nitrogen (N) or phosphorus (P) most commonly limits phytoplankton productivity in coastal waters (Ryther and Dunstan 1971; Hecky and Kilham 1988); which of these elements controls oceanic primary production is still being debated (Falkowski 1997; Tyrrell 1999). In estuaries, there can be a shift from P to N limitation during the spring to summer transition (Conley 2000), or the limiting nutrient can depend on the mix of fresh and marine waters and the severity of anthropogenic nutrient loading (Yin *et al.* 2001). The growth of diatoms in coastal regions may also at times be limited by the concentration of silicon (Si) (Officer and Ryther 1980; Justić *et al.* 1995; Conley 2000). Of course, which nutrient limits phytoplankton growth in coastal waters determines what nutrient (N or P) must be controlled to reduce impacts from agricultural, and other point and non-point sources (Conley 2000; Pinckney *et al.* 2001; Boesch 2002). During the past 20 years, the simple view of limitation by a single nutrient or resource has been replaced by the realization that, in some parts of the world, phytoplankton growth can be limited by more than one nutrient or resource (Aumont *et al.* 1993; Klausmeier *et al.* 2004a; Arrigo 2005). For example, Yin *et al.* (2001) found P and Si co-limitation of diatoms in a coastal plume of the Pearl River estuary in the South China Sea. Diatoms in the St. Lawrence estuary became simultaneously deficient in N and Si (Levasseur *et al.* 1990). Multiple resource co-limitation may also include light plus nutrients (Cloern 1999), including trace metals (Timmermans *et al.* 2001; Mills *et al.* 2004; Arrigo 2005); most examples of this seem to be from offshore, oligotrophic waters, which have been shown to be iron (Fe) limited (e.g. Mills *et al.* 2004). However, the elevated concentrations of N in eutrophic coastal waters may result in high primary production, with a consequent high demand for Fe, especially when nitrate is the N source. That, in combination with the majority of Fe being biologically unavailable because it is bound to

particles and organics, can result in Fe also being a limiting micronutrient in coastal wasters (e.g. Zhang 2000).

To a large degree, our current approach for examining nutrient limitation stems from a now classic paper that Alfred Redfield wrote in 1934, in which he proposed that the N:P ratio of plankton (16:1 by atoms) causes the ocean to have a remarkably similar ratio of dissolved nitrate to phosphate (Redfield 1958; Falkowski 2000). A deviation from this so-called Redfield ratio of 16:1 in phytoplankton has been used as an indication of which nutrient is limiting. Thus, it has been assumed that phytoplankton are N-limited at N:P < 16:1 and P-limited at N:P > 16:1. In reality, the Redfield ratio of phytoplankton has been shown to vary considerably due to species-specific differences, to variable amounts of these elements being stored by cells experiencing differing degrees of nutrient limitation, or to different growth strategies that result in dissimilar proportions of ribosomes and proteins (Geider and La Roche 2002; Klausmeier *et al.* 2004b; Lagus *et al.* 2004; Arrigo 2005; Sarthou *et al.* 2005). The 16:1 ratio is no longer considered a universally optimum value, but rather an average stoichiometry of phytoplankton in the ocean (Klausmeier *et al.* 2004b).

Applying the N:P ratio of 16:1 for these elements in seawater has similarly been used to assess nutrient limitation; seawater Redfield ratios greater than 16:1 are interpreted as indicative of P limitation and, conversely, low ratios are suggestive of N limitation. In the same way, because diatoms require Si and N in approximately a 1:1 (molar) ratio, the ratio of Si:N has been used to assess the possible limitation by Si (Brzezinski 1985; Levasseur and Therriault 1987). However, direct application of these principles is problematic for coastal systems (Pinckney *et al.* 2001). Nutrient concentrations may change rapidly in dynamic coastal systems. Nutrients are rapidly regenerated and may have a short turnover time, so that uptake of nutrients from inorganic forms to the phytoplankton may be more important in determining which nutrients are limiting growth rates than inorganic nutrient concentrations, which may only indicate which nutrient limits the theoretical maximum biomass. Organic nutrients may also be important (Glibert *et al.* 2006). In the case of diatoms, Si utilization is species specific and may be affected by the cell growth cycle (Brzezinski 1985). One can therefore not always predict which nutrient limits phytoplankton growth, silicate or nitrate, by the cellular Si:N ratio alone (Kudo 2003). Nevertheless, ratios of these elements in seawater may still be applied cautiously as an indication of nutrient sufficiency or deficiency, provided that other resources (e.g. light) are not limiting.

A way of determining if the concentration of a nutrient in a body of seawater is limiting to growth is to examine the capability of phytoplankton cells to take up the nutrient at the ambient concentration. For a given nutrient, the specific uptake rate (V_{Nut}) follows the Michaelis-Menten saturation equation:

$$V_{Nut} = V_{max} * \frac{[Nut]}{[Nut] + Ks} \qquad (1)$$

where: V_{max} = maximum rate of nutrient uptake at an infinite substrate concentration;
[Nut] = nutrient concentration;
Ks = half-saturation constant, i.e. the nutrient concentration at one half of V_{max};
[Nut] = ambient concentration of the nutrient.

The nutrient concentration in seawater is compared to the value of the half-saturation constant (Ks). If the ambient concentration of a nutrient is < Ks for uptake, it has been argued that the phytoplankton in that body of water will be limited by that nutrient (at [Nut] = Ks, V_{Nut} = one half of V_{max}). However, Ks values are known to vary with many factors, including species, the form of the nutrient, and whether they are applied to nutrient uptake or phytoplankton growth rate; the range can be wide. Sarthou *et al.* (2005) compiled Ks values for silicate, nitrate, phosphate and iron, but only for a number of diatoms.

Change in the N:P Redfield ratio, or in the ratios of other nutrients (e.g. N:Si, Si:P), is one mechanism by which nutrients may select for a particular class of phytoplankton. Smayda (1989, 1990) developed the nutrient ratio hypothesis to explain changes in the dominance of particular harmful algal bloom species over time due to changing nutrient loading patterns in different eutrophied bodies of seawater around the world. For example, a decrease in N:P and Si:P ratios (because of an increase in P concentration) over 20 years in the Rhine River, the Baltic Sea, Dutch coastal waters, parts of the North Sea and Black Sea, have resulted in significant, more frequent HAB species that do not require Si (e.g. *Phaeocystis pouchetii*, *Nodularia spumigena*, and *Exuviaella cordata*). Ratios of Si:N have decreased in the northern Gulf of Mexico as a result of increased N and decreased Si in the Mississippi River outflow, and this is associated with increased numbers of toxic, lightly silicified *Pseudo-nitzschia* spp. (Parsons *et al.* 2002). There are thus associations between both the concentration of nutrients and their ratios and the incidence of HABs. Whether this is a direct link or not is still under debate (Andersen 1989; Paerl and Whitall 1999; Hallegraeff 2003).

The present study was carried out on Prince Edward Island (PEI), located in the southern Gulf of St. Lawrence (Fig. 1). Bivalve aquaculture has expanded rapidly in recent decades in Canada, with a disproportionate amount of the industry located in PEI. In 2004, 77% of the mussels (*Mytilus* spp.) harvested in Canada, and 55% of the bivalves, came from PEI; the aquaculture industry in PEI was valued at $30 million $CAN (DFO 2005). The literature on the mechanisms by which bivalves in general, and mussels in particular, can influence ecosystem properties is extensive, and there have been many reviews (e.g. Smaal and Prins 1993; Dame 1996; Dame and Prins 1998; Cranford *et al.* 2003). Farmed mussels convert suspended particulate matter (SPM) into biomass and into rapidly sinking faeces and pseudofaeces, and release dissolved nutrients directly in their metabolic wastes. In so doing, they transfer nutrients from the water column to the benthos, and may retain nutrients in coastal systems and more rapidly recycle dissolved nutrients into the water column than would otherwise have been the case. The intensity of mussel aquaculture in some PEI inlets is sufficient to dominate nutrient cycling (Cranford *et al.*, submitted), with possible consequences on phytoplankton abundance and species composition. Farmed mussels may also directly lower the concentrations of phytoplankton if their feeding activity outstrips phytoplankton growth. In addition, much of PEI is in agricultural use (predominantly potato production) and discharges of agricultural chemicals, including excess nutrients from fertilizer use, are significant (Cranford *et al.*, submitted).

Some inlets on PEI have been described as being subject to eutrophication. The most striking symptoms of this have been the more frequent and dense blooms of sea lettuce (*Ulva lactuca*), which decompose, causing anoxic conditions (Raymond *et al.* 2002). Measurements by the Province of PEI and Environment Canada have indicated that concentrations of total N, NO_3

and P have increased in PEI estuaries since the 1970s, and this change has been related to agriculture (Somers *et al.* 1999; Raymond *et al.* 2002). Phytoplankton chlorophyll levels have been measured systematically only since 1991, and only at three inlets, making it difficult to draw conclusions about increasing trends and relationships with nutrient concentrations. On the other hand, Meeuwig *et al.* (1998) found positive correlations between chlorophyll and both total N and total P in 15 PEI inlets sampled from May to August, 1996. Their data did not allow them to come to any firm conclusions about whether N or P was the key limiting nutrient, but they did quantify the importance of turbidity and herbivory (including that by farmed mussels) in determining chlorophyll biomass. Furthermore, they suggested that the relative concentrations of N and P may be a function more of nutrient loading than of uptake by the phytoplankton, because of the relatively short residence times of the estuaries. This example illustrates the challenges in interpreting nutrient limitation from Redfield ratios.

One impediment to mussel aquaculture development within PEI inlets has been the incidence of HABs (Bates 2006). Historically, these inlets have been impacted mainly by HABs composed of the diatom genus *Pseudo-nitzschia*, some species of which produce domoic acid, the neurotoxin that causes amnesic shellfish poisoning (reviewed by Bates 1998, 2004; Bates *et al.* 1998). The first major outbreak was in Cardigan Bay during the late fall and early winter of 1987, which caused the death of at least three people and the sickness of over 100. The toxin source was identified as *Pseudo-nitzschia multiseries*; this was the first known instance of a diatom producing a phycotoxin. Toxic blooms in the subsequent two years were smaller, and the next closures were later, on the north shore: New London Bay (1991, 1992, 1994), Malpeque Bay (1991, 2001), and Mill River (2000). In the spring of 2002, most of the southern Gulf of St. Lawrence, including northern PEI, was closed due to domoic acid, traced to *Pseudo-nitzschia seriata* (Bates *et al.* 2002).

Laboratory studies have shown that nutrients, in particular Si and P, when present at limiting concentrations, trigger the production of domoic acid by *P. multiseries*, *P. seriata* and some other *Pseudo-nitzschia* species not yet found in the southern Gulf of St. Lawrence (reviewed by Bates *et al.* 1998; Bates and Trainer 2006). Provided that light for photosynthesis and N are in excess, domoic acid production begins when the division rate of *Pseudo-nitzschia* cells slows or ceases due to the depletion of Si and P from the growth medium. More recent studies have shown that stress caused by copper (Cu) toxicity and Fe limitation also triggers domoic acid production (Wells *et al.* 2005; Bates and Trainer 2006). Other laboratory studies have shown that *P. multiseries* outcompetes other algae at low Si:N ratios, in contrast to other diatoms (Sommer 1994). Thus, both the concentration and the relative amounts of certain nutrients can be important in favouring the growth of *Pseudo-nitzschia* species and in increasing their toxicity.

In this report, we compare the results of phytoplankton and nutrient measurements in 14 PEI inlets in order to look for relationships between species composition (especially for the *Pseudo-nitzschia* species) and nutrient levels in natural populations during the late summer and fall. We also consider the likelihood of nutrient limitation within the phytoplankton community by comparing ambient nutrient concentrations with the inherent ability of the phytoplankton to take up the nutrients at low concentrations. The study was carried out in the context of the Environmental Science Strategic Research Fund (ESSRF) program "Integrated Ecosystem Studies for Modelling Mussel Aquaculture-Environment Interactions" (Cranford *et al.* 2006).

MATERIALS AND METHODS

Sampling Program

Samples for nutrients and phytoplankton were collected from 14 PEI inlets (Fig. 1), in the late summer and fall of 2001, 2002 and 2003 (Fig. 2). Sampling positions are shown in Table 1, and the exact sampling locations within the inlets are shown on the maps in Appendix A. Sampling began at the time of year when potentially toxic *Pseudo-nitzschia* spp. had generally started to bloom in the past (Bates *et al.* 1998; Bates 2004). The earliest sampling date was September 3 (in 2002) and the latest was December 17 (in 2001); sampling was terminated when ice began forming in the inlets. Personnel from the Canadian Food Inspection Agency (CFIA) collected water samples from the western half of PEI, as an adjunct to their surveillance program of shellfish growing areas for shellfish biotoxins, which is part of the Canadian Shellfish Sanitation Program (CSSP). Water samples from the eastern half of PEI were collected from small boats by the Prince Edward Island Department of Fisheries, Aquaculture and Environment (now called the Department of Agriculture, Fisheries, and Aquaculture; DAFA), as part of their PEI Mussel Monitoring Program (MMP) that provides information to mussel growers on mussel spatfall, mussel meat yields, water temperature, and the presence of predators, fouling organisms, and potentially toxic algal species (Smith 2001, 2002, 2003).

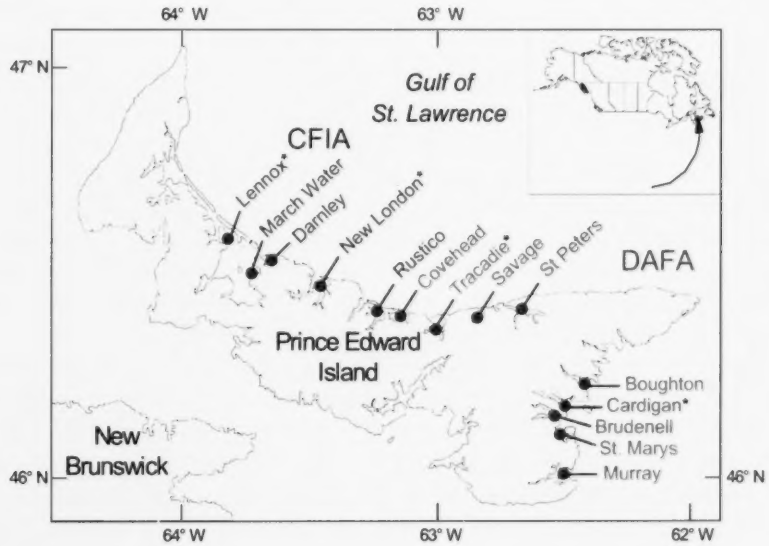

Fig. 1. Nutrient and phytoplankton sampling locations on Prince Edward Island (PEI); late summer and fall of 2001–2003. Samples from inlets on the western half of PEI were collected by the Canadian Food Inspection Agency (CFIA); those on the eastern half were collected by the PEI Department of Agriculture, Fisheries and Aquaculture (DAFA). Locations shown with an asterisk (*) indicate inlets where analyses of the total phytoplankton community were carried out multiple times in all three years; at the remaining locations, only one sample per year was analyzed for phytoplankton.

Table 1. Sampling locations on Prince Edward Island.

Inlet	Latitude	Longitude
Boughton River	46° 16.08' N	62° 29.10' W
Brudenell River	46° 12.12' N	62° 36.66' W
Cardigan River	46° 13.44' N	62° 34.08' W
Covehead Bay	46° 25.02' N	63° 8.34' W
Darnley Basin	46° 33.18' N	63° 40.02' W
Lennox Channel (Malpeque Bay)	46° 36.30' N	63° 52.98' W
March Water (Malpeque Bay)	46° 31.20' N	63° 42.00' W
Murray River	46° 2.46' N	62° 31.92' W
New London Bay	46° 29.46' N	63° 27.96' W
Rustico Bay	46° 25.32' N	63° 13.98' W
Savage Harbour	46° 24.54' N	62° 51.30' W
St. Marys Bay	46° 7.80' N	62° 30.84' W
St. Peters Bay	46° 25.62' N	62° 39.24' W
Tracadie Bay	46° 22.92' N	63° 1.68' W

Water samples for both nutrients and phytoplankton were collected simultaneously, according to the procedures detailed in Smith and Pauley (unpublished document, 1990). Briefly, a sample that integrated the water column from the surface to near the bottom was collected with a 9.1 m long integrating sampling tube (3 cm inner diameter), made of food-grade material for the dairy industry. The end of the tube was kept above the bottom (to avoid collecting suspended sediments) by means of a sounding weight hung 0.5 m from the tube. At each sampling location, the integrating tube system was lowered to the bottom and the water in the tube was trapped by closing a valve at the top of the tube. The sampled water was then drained into a carboy. Five such casts were carried out in succession and mixed together in the carboy, in order to minimize problems of horizontal patchiness. Unfiltered water samples for silicate, phosphate, nitrate, nitrite, and ammonia analysis were placed in washed 30 mL high density polyethylene bottles supplied by the nutrient laboratory of the Marine Chemistry Section (DFO, Bedford Institute of Oceanography, Dartmouth, NS) and frozen until analysis. Water samples for phytoplankton analysis were placed in 250 mL glass jars containing 10 mL of formalin acetic acid (FAA) preservative, yielding ~2% (v/v) preservative. The FAA solution was made by mixing 500 mL of full-strength (40%, w/v) formaldehyde solution with 500 mL of glacial acetic acid. We found that diatoms, other than *P. pungens* cells, were not well enough preserved for scanning electron microscopy (SEM) analysis after ca. 2.5 years of storage in FAA. The other phytoplankton groups were not examined by SEM.

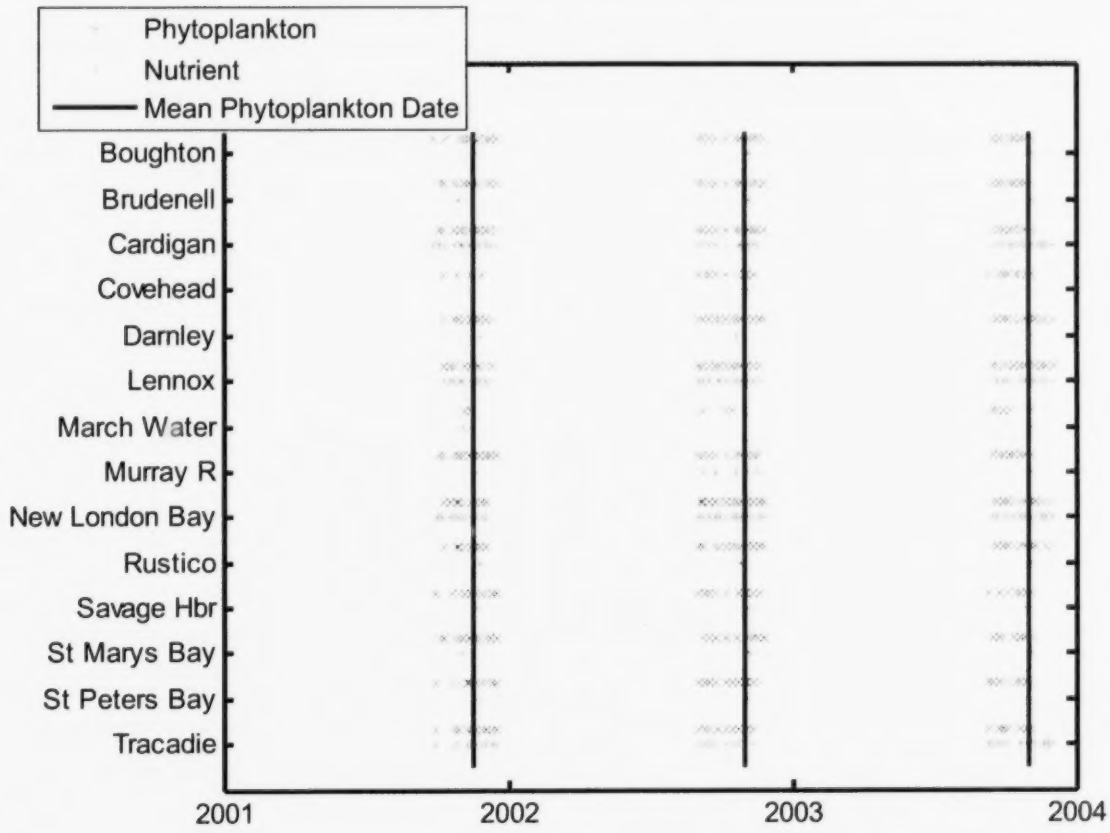

Fig. 2. Phytoplankton and nutrient sampling dates in each of the PEI inlets. Vertical lines are the average date of phytoplankton sampling for inlets sampled only once per year for phytoplankton.

As shown in Figures 1 and 2, detailed time series phytoplankton data (i.e. total community composition) for 2001-2003 are only available for the Cardigan River, Lennox Channel, New London Bay and Tracadie Bay sampling sites; for other inlets, phytoplankton data are only available once or twice (e.g. March Water in 2001) per year, except that no phytoplankton data are available for March Water in 2002. Time series nutrient data are available for all inlets in all years: nutrient data are available for most locations for most dates on which phytoplankton data are available, but not all. Nutrient samples were collected over slightly different periods in the three years of sampling (Fig. 3).

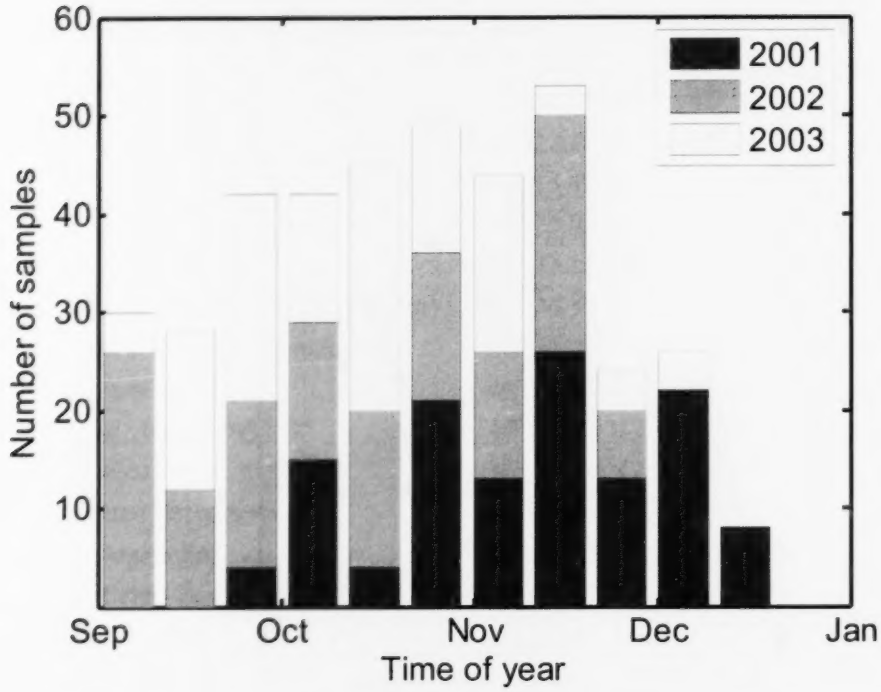

Fig. 3. Dates of nutrient sample collection for the three years of the sampling program. The total number of samples analyzed was 391.

Nutrient Analysis

All nutrient analyses were performed using colorimetric or fluorometric techniques on a Technicon AutoAnalyzer II (AA II) segmented flow analyzer. Our implementations of standard colorimetric methods for silicate (Si), phosphate (PO_4), nitrate (NO_3), and nitrite (NO_2) are described in detail in Strain and Clement (1996). The 'nitrate' analysis actually measures the sum of nitrate and nitrite; nitrite is a small fraction of the nitrate in seawater. In this paper, we will refer to (nitrate + nitrite) as nitrate or NO_3. Ammonia (NH_3) samples were analyzed with a fluorometric technique (Kérouel and Aminot 1997), based on the reaction between ammonia, orthophthaldialdehyde (OPA), and sulfite. Our implementation of the OPA technique is essentially identical to that described by Kérouel and Aminot (1997), except for the fluorometer: we used a model 2001A Fluoro-Tec® fluorometer (St. John Associates, Beltsville, MD, USA). We will refer to the total inorganic nitrogen as TIN; it is derived by summing the nitrate and ammonia measurements and is equal to $NO_3 + NO_2 + NH_3$. All nutrient data are in units of micromoles per litre (μM).

The precision and detection limits for the analyses are routinely determined as part of each AA II run. We estimated precision from the coefficient of variation of the check standards in the run; detection limit is three times the standard deviation of the blanks in the run. Table 2 lists the

mean precisions and detection limits for the nine AA II runs in which the samples from this study were analyzed.

Table 2. Precisions (%) and detection limits (μM) for the nutrient analyses.

	Silicate	Phosphate	Nitrate	Nitrite	Ammonia
Precision (%)	0.78	2.2	1.06	1.15	3.10
Detection limit (μM)	0.20	0.051	0.10	0.030	0.31

Phytoplankton Analysis

Phytoplankton were identified and enumerated by Murielle LeGresley (Fisheries and Oceans Canada, St. Andrews Biological Station, St. Andrews, NB). Water samples (50 mL; occasionally 10 mL or 25 mL, when phytoplankton concentrations were higher) were allowed to settle for ca. 16 hours in an Utermöhl settling chamber (Utermöhl 1958). Dominant and other species were counted and identified by inverted light microscopy at 200X, and occasionally at 400X to verify taxonomic details. It should be pointed out that the term "phytoplankton", as used here, excludes the majority (by numerical abundance) of small photoautotrophic cells that do not settle completely in Utermöhl chambers and which are underestimated by microscopy (cf. Li 2002; Li *et al.* 2006a).

Pseudo-nitzschia species cannot be identified definitively by light microscopy, so they were initially placed into the categories shown in Table 3, based on cell width and shape. Cells with a valve width less than 3 μm fall into the *delicatissima* group and those greater than 3 μm were placed in the *seriata* group (Hasle and Syvertsen 1997). Scanning electron microscopy (SEM; see below) was later used to definitively identify cells in these categories, although representatives from all groupings could not be found in the SEM preparations.

Table 3. Categories used for counting *Pseudo-nitzschia* spp. by light microscopy (LM). *Pseudo-nitzschia multiseries* and *P. pungens* cannot be distinguished by LM, so are counted together in this report. When available, scanning electron microscopy images confirmed the identity of cells in each category.

Code	Group	Cell width (µm)	Cell length (µm)	Cell Description	Identity
Ps-n #1	*delicatissima*	< 2	~70	Linear, hair-like; cell tip overlap: 1/10 of cell length	*P. delicatissima*
Ps-n #2a	*delicatissima*	> 2	~75	Lanceolate shape; cell tip overlap: 1/7 of cell length	*P. calliantha*
Ps-n #2b	*delicatissima*	> 2	~100	Same shape as Ps-n 2a, but longer; likely a "younger" cell	*P. calliantha*
Ps-n #3	*seriata*	3–5	100 – 110	Heavily silicified	*P. multiseries* or *P. pungens*
Ps-n #4	*seriata*	~8	~150	Asymmetrical valves	*P. seriata*
Ps-n #5	*seriata*	5–6	~75	Symmetrical valves	*P. fraudulenta*
Ps-n #6	*seriata*	~7	~88	Asymmetrical in valve view; cell tip overlap: 1/5 of cell length	*P.* cf. *subpacifica*
None	*delicatissima*	2.5–3.7	12–39	Blunt, rounded ends; cell tip overlap: 1/10 of cell length	*P. americana*

Scanning Electron Microscopy

Scanning electron microscopy (SEM) examination was used to determine the identity of the *Pseudo-nitzschia* species indicated in the categories designated in Table 3. For category Ps-n #6, we were unable to obtain the appropriate SEM images from which to make a definitive identification. However, the wide cells are similar to the drawings of *Pseudo-nitzschia subpacifica* in Hasle (1965; Plate 1, Fig. 9, chain in valve view), which are distinct from *Pseudo-nitzschia fraudulenta*; in valve view, the former has one convex margin and the other is more or less straight, whereas the latter has symmetrical margins. *Pseudo-nitzschia americana* was observed in low numbers only in 2003, and did not fall into any of the categories. It is easily identifiable by light microscopy (LM) in fresh samples due to its characteristic blunt ends and short cells (Kaczmarska *et al.* 2005).

The majority of SEM samples were processed at the Digital Microscopy Facility by James Ehrman (Mount Allison University, Sackville, NB), using the method outlined in Kaczmarska *et al.* (2005). Samples were cleaned using a Millipore vacuum filtration apparatus containing a 25 mm diameter, 3 µm pore-size polytetrafluoroethylene (PTFE) membrane (General Electric Osmonics, Minnetonka, MN, USA). Material was first washed with 250 mL distilled water, re-suspended in 5 mL distilled water and cleaned by adding 10 mL each of concentrated sulfuric and nitric acids in a boiling water bath for 60 min. Samples were washed again with 250 mL distilled water in the filtration apparatus and re-suspended in 5 mL distilled water. Subsequently, 0.5-1.0 mL of the cleaned sample was dispersed on the same type of 3 µm filters. Filters were mounted on aluminum stubs using double-sided tape, rimmed with colloidal carbon and coated with ~10 nm of gold in a Hummer 6.2 sputtering unit (Anatech Ltd., Springfield, VA). For SEM transmitted electron detector (TED) examination, one drop of cleaned bulk sample was diluted to 10:1 and 100:1, and single drops were dried onto 400-mesh copper grids bearing pure carbon support films. SEM and TED were performed using a JEOL JSM-5600 SEM operating at 10 kV and 8 mm working distance. TED imaging, which simulates transmission electron microscopy, was performed using the detector described by Ehrman and Kaczmarska (2001). The identity of *Pseudo-nitzschia* species was based on the morphometrics given in Hasle and Syvertsen (1997), Lundholm *et al.* (2003), and Kaczmarska *et al.* (2005).

A subset of samples for SEM was also prepared and examined by Murielle LeGresley, at the St. Andrews Biological Station (St. Andrews, NB), to determine the proportion of *Pseudo-nitzschia* species. These samples were acid cleaned as above and examined using an Hitachi S-2400 SEM. All *Pseudo-nitzschia* cells were identified, until a count of 100 was reached, or until no more such cells were observed, whichever came first. The proportion of each species was then reported as a percent.

Statistics

Differences between the timing and frequency of sampling in the phytoplankton and nutrient datasets present some challenges in looking for possible links between nutrient levels and phytoplankton abundances and species composition. A further complication arises in the phytoplankton data because the protocol used for phytoplankton enumeration for the ten inlets sampled only once in 2001 was different from that used for the rest of the samples. In those cases, species other than *Pseudo-nitzschia* were only qualitatively identified, not counted. Such samples are equivalent to the others when all the phytoplankton data are analyzed in terms of presence / absence, but the 2001 data for those ten inlets has to be eliminated when the data are analyzed quantitatively.

Most of the statistics used in this report were calculated using the built-in functions of the Statistics Toolbox in Matlab® v. 7.0 (The MathWorks Inc., Natick, MA, USA). The functions used, including one-way analysis of variance, t-tests with Bonferroni adjustment for multiple comparisons, Jarque-Bera normality test, hierarchical cluster analysis, and Spearman correlations, are straightforward implementations of standard techniques. We also used two non-parametric methods to test for differences between means: the Mann-Whitney U-test and the sign test. In Matlab, the former is called the Wilcoxon rank sum test. We used Systat® v. 10 (SPPS

Inc. Chicago, IL USA) for the principal component analysis (PCA), which included a varimax rotation. Again, this is a standard technique.

In one part of our analysis, we wanted to compare phytoplankton composition and abundance from different inlets and different years. For this purpose, we chose to use the Bray-Curtis similarity index (Bray and Curtis 1957). In a thorough review of the available techniques, Beals (1984) concluded that the Bray-Curtis index is one of the better techniques available. He also noted that the Bray-Curtis index (BC) was equally useful in analyzing quantitative data to give information on species assemblages based either on abundances or presence / absence data. Although BC was not available in Matlab, it was easily calculated from the defining equation (Bray and Curtis 1957):

$$BC_{ij} = \frac{2x\sum_{k} \min(n_{ik}, n_{jk})}{\sum_{k} n_{ik} + \sum_{k} n_{jk}}$$

where: BC_{ij} = BC similarity index between samples i and j;
n_{ik}, n_{jk} are the abundances of species k in samples i and j;
and the sums are over all species k found in either sample i or j.

BC_{ij} varies from 0 (no species in common) to 1 (identical species distributions).

For use with presence / absence data, the quantitative data are simply replaced by 1's (present) or 0's (absent).

RESULTS

Nutrients

Figures 4 and 5 show the distribution of nutrient concentrations observed in the 14 PEI inlets over the three-year sampling program (2001–2003).

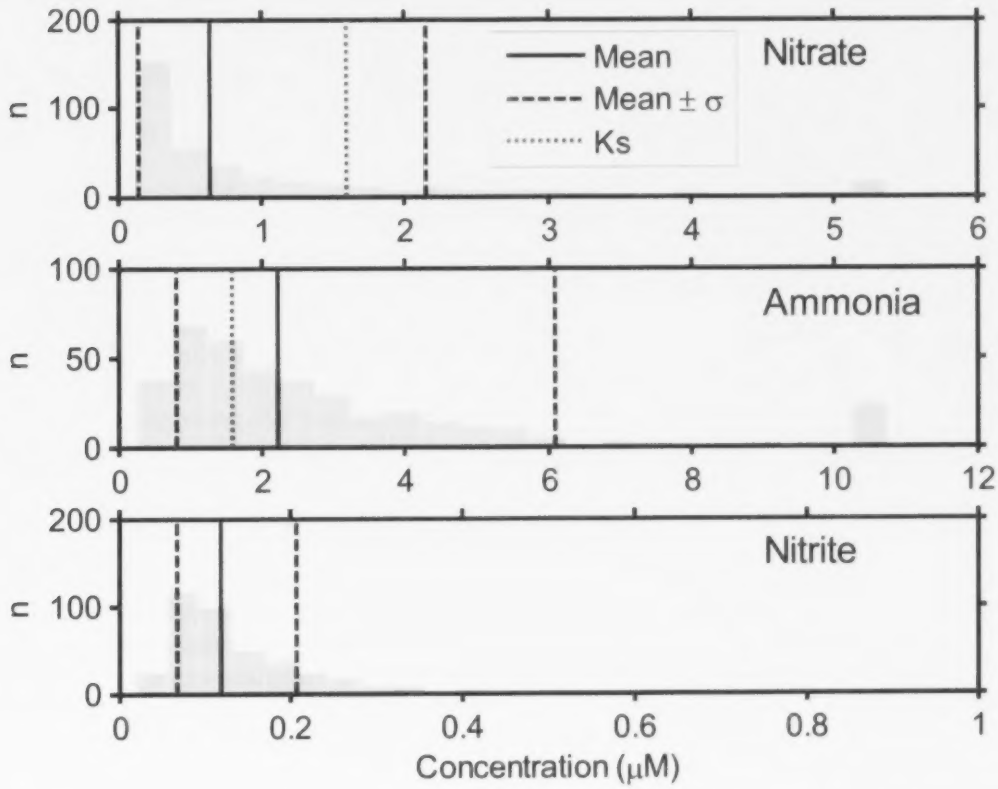

Fig. 4. Distribution of inorganic nitrogen concentrations in PEI inlets. The solid blue vertical lines indicate the mean concentrations and the dashed blue lines the mean ± 1σ after transformation, as described in the text; the dotted red lines are the mean half-saturation constants (Ks) for nutrient uptake by diatoms reported by Sarthou *et al.* (2005). Some extreme values are not shown on these plots.

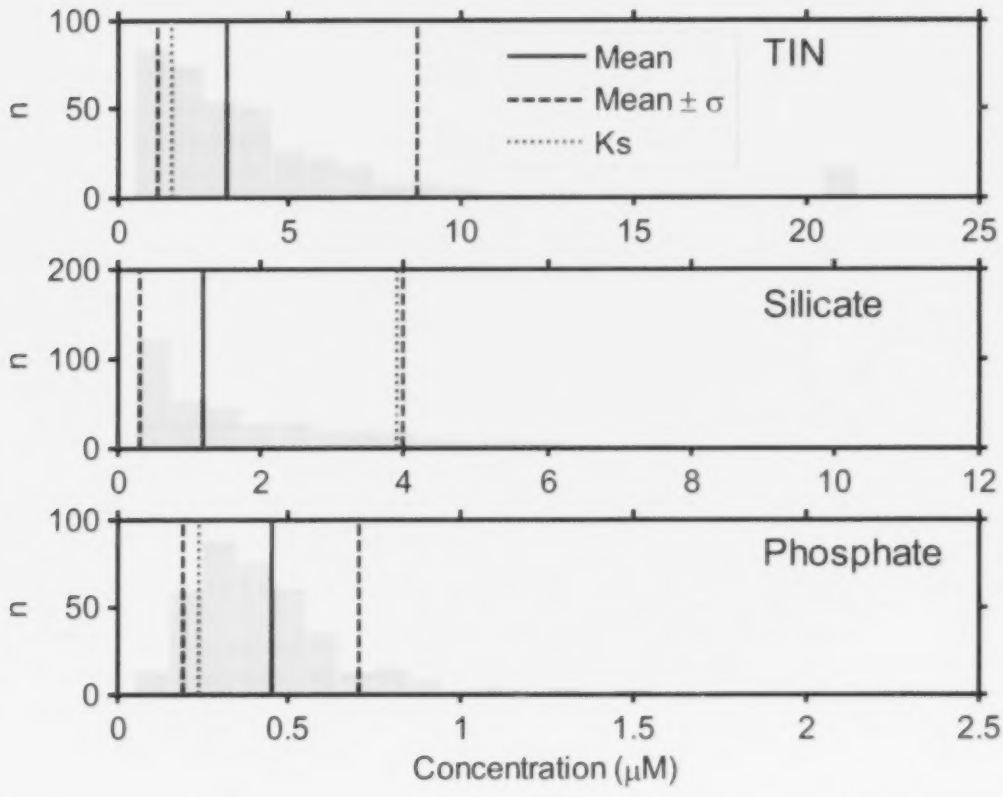

Fig. 5. Distribution of total inorganic nitrogen (TIN), silicate and phosphate concentrations (in μM) in PEI inlets. The solid blue vertical lines indicate the mean concentrations and the dashed blue lines the mean ± 1σ after transformation, as described in the text; the dotted red lines are the mean half-saturation constant (Ks) for nutrient uptake by diatoms reported by Sarthou *et al.* (2005). Some extreme values are not shown on these plots.

Calculations of means and standard deviations for these distributions were complicated by the fact that the concentrations of the nitrogen species and silicate are clearly not normally distributed. Logarithmic transformation of the concentrations $\log_{10}(X)$ for NH_3, NO_2 and TIN; $\log_{10}(X + 0.1)$ for NO_3 and Si (each of which have some zero values) made these distributions much closer to normal. In fact, the Jarque-Bera statistic for normality was reduced by between one and three orders of magnitude by these transformations. The phosphate distribution was not normally distributed either (Jarque-Bera test, $p << 0.01$), but its normality was not improved by logarithmic transformation. The lines showing the values for the means, mean - 1σ, mean + 1σ on Figures 4 and 5 are based on these logarithmic transformations for all nutrients except phosphate, with the result that these ± 1σ lines are asymmetric around the mean. The phosphate data were analyzed without transformation. Statistics for each of the nutrients for individual inlets and the entire dataset are shown in Appendix B.

Figure 4 shows that the inorganic nitrogen in these inlets was dominated by ammonia in the late summer and fall: the mean ammonia concentration (2.23 μM) was ~3.5 times higher than that of nitrate (0.64 μM) and ~19 times greater than that of nitrite (0.118 μM). The mean total inorganic nitrogen was only 3.22 μM, a value that is well below values thought to indicate eutrophication and is only twice the mean value for the half-saturation constant for diatoms (Ks = 1.6 μM) reported by Sarthou *et al.* (2005). Although Ks values are known to vary with many factors, including species, the form of the nutrient, and whether they are applied to nutrient uptake or phytoplankton growth rate (Sarthou *et al.*'s compilation includes both), they are used here to provide some context for the nutrient levels from the perspective of the phytoplankton. In other words, not only were the inorganic nitrogen levels not elevated, but most of the time they were approaching levels low enough to limit phytoplankton growth rates. Extreme values do occur: there were 16 ammonia concentrations > 20 μM, and four nitrate concentrations > 10 μM, but such high values were not the norm.

Silicate and phosphate levels were also low most of the time, with mean values of 1.20 and 0.45 μM, respectively. Silicate levels were also usually lower than the Ks value reported for diatoms (3.9 μM; Sarthou *et al.* 2005). Phosphate was the only nutrient whose levels were more often than not greater than the Ks value (0.24 μM) for diatom growth (Fig. 5).

The inlet-by-inlet statistics (Appendix B) suggest that there may have been differences between the inlets. This hypothesis can be tested with a one-way analysis of variance (ANOVA), again using the transformed data as described above, which clearly shows that at least one inlet was different from the others on the basis of any of the nutrients ($p << 0.001$ for all five nutrients). The pairs of inlets that are significantly different can be identified by using t-tests, after a Bonferroni adjustment to insure that spurious differences do not result from the large number (91) of pairs of inlets being compared. Table 4 shows which inlets were different on the basis of which nutrients. Despite the complexity of these comparisons (64 pairs of inlets can be distinguished by comparing the five nutrients), a few general trends that are responsible for many of the differences may be discerned from the table. The levels of all the nitrogen species, and to a lesser extent silicate, were lower in Lennox Channel than in many other inlets: these low levels alone were part of 27 of the 64 significant differences. High phosphate and low nitrate levels in March Water accounted for 17 more, and explained 13 out of the 18 significant differences based on phosphate. Cardigan River and St. Marys Bay were low in nitrite compared to five other inlets each, with mixed results for ammonia, silicate, and phosphate.

Most of the differences between inlets are probably not due to temporal aliasing: most of the inlets were sampled at a similar time and frequency over the whole sampling program (Fig. 2). However, March Water was sampled less frequently than the other inlets, and only during the first part of the season. It is possible that the distinctiveness of March Water is due to these sampling differences. Nevertheless, the fact that the other significant differences in nutrient levels between inlets can be detected by comparisons as coarse as comparing the means of all the available data suggests that differences in nutrient conditions may have been substantial.

Table 4. Significant differences between pairs of inlets on the basis of nutrient levels. Significance was assessed at p = 0.05, using two-tailed t-tests after Bonferroni adjustment for the large number of comparisons. Pairs of inlets with blank entries in the table, or that do not appear in the table, did not differ significantly on the basis of any of the nutrients. Nutrients in red italics are those in which the mean nutrient in the inlet in the row was less than the value for the inlet in the column; underlined blue indicates that the mean nutrient in the inlet in the row was more than the value for the inlet in the column.

	Darnley Basin	Lennox Channel	March Water	New London Bay	Rustico	St Peters Bay	Tracadie Bay
Boughton River		NO_3	*PO_4*				
Brudenell River		NO_3, NH_3	*PO_4*		*NO_2*		
Cardigan River	*NO_2*	Si, NH_3	*PO_4*	*NO_2*	*NO_2*	*NO_2*	PO_4, *NO_2*
Covehead Bay		NO_3	*PO_4*, NO_3				
Darnley Basin		NO_3, NO_2, NH_3	*PO_4*	PO_4			PO_4
Lennox Channel	See Darnley–Lennox		*PO_4*	*NO_3*, *NO_2*	*Si*, *NO_3*, *NO_2*, *NH_3*	*Si*, *NO_3*, *NO_2*, *NH_3*	*Si*, *NO_3*, *NO_2*, *NH_3*
March Water	See Darnley –March Water	See Lennox–March Water		PO_4	PO_4, *NO_3*	PO_4, *NO_3*	PO_4, *NO_3*
Murray River		Si, NO_3	Si, *PO_4*	Si, PO_4	*NO_2*		PO_4
Savage Harbour		NO_3, NH_3	*PO_4*				
St Marys Bay	*NO_2*		*PO_4*	*NO_2*	*NO_2*, *NH_3*	*NO_2*	*NO_2*

It is possible to do a similar comparison between the years of the sampling program. Once again, a one-way ANOVA based on any of the nutrient concentrations shows that at least one year is different from the other two ($p < 0.01$ for all five nutrients). The corresponding pair-wise analyses are shown in Table 5. Because the nutrient sampling was conducted over slightly different periods in the different years of the program (Fig. 3), it is not possible to separate real year-to-year variations from possible seasonal aliasing of the data. For example, sampling both started and finished latest in 2001. However, attempts to merge data for different years for

individual inlets for plotting concentrations versus Julian day led to very noisy results, suggesting that at least some real year-to-year variability does occur in these data. Both the differences between years and the differences between inlets make it difficult to generalize across inlets or years. Some typical seasonal patterns for the nutrients are shown in Figures 6-10, with the data separated by inlet and year.

Table 5. Significant differences between sampling years on the basis of nutrient levels. Significance was assessed at p = 0.05, using two-tailed t-tests after Bonferroni adjustment for the number of comparisons. Nutrients in red italics are those in which the mean nutrient in the year in the row was less than the value for the year in the column; underlined blue indicates that the mean nutrient in the year in the row was more than the value for the year in the column.

	2002	2003
2001	*Si, PO_4,* $\underline{NH_3}$	*Si, PO_4,* $\underline{NO_2}$, $\underline{NH_3}$
2002		$\underline{NO_3}$, $\underline{NO_2}$

Figure 6 shows some examples of nitrate levels in the four inlets for which times series phytoplankton data are also available. The dominant feature of these seasonal patterns is that nitrate levels were very low through much of the late summer / fall period. This is perhaps surprising, given the very high levels of nitrate in some freshwaters flowing into these inlets. For example, in the fall of 2003, nitrate levels from agricultural run-off reached 150 µM in Winter River, which flows into Tracadie Bay, but nitrate is effectively removed from the Bay very close to the mouth of the River (Strain, unpublished data; Cranford *et al.*, submitted). Brief pulses of high nitrate levels did occur throughout this period of the year (e.g. Tracadie Bay in 2002; Cardigan River in 2003), and were probably due to land-based inputs "leaking" through into the more open waters of the inlets. In addition, most inlets showed some increases in nitrate levels late in the season due to increases in shelf concentrations at this time in the offshore seasonal cycle; this trend was especially evident in Rustico Bay (not shown), where it occurred in all three years of the sampling program, with nitrate reaching 22.6 µM in 2002. These increases were more or less persistent, as some late season growth depleted the nitrate concentrations in some inlets (e.g. Cardigan River, 2002).

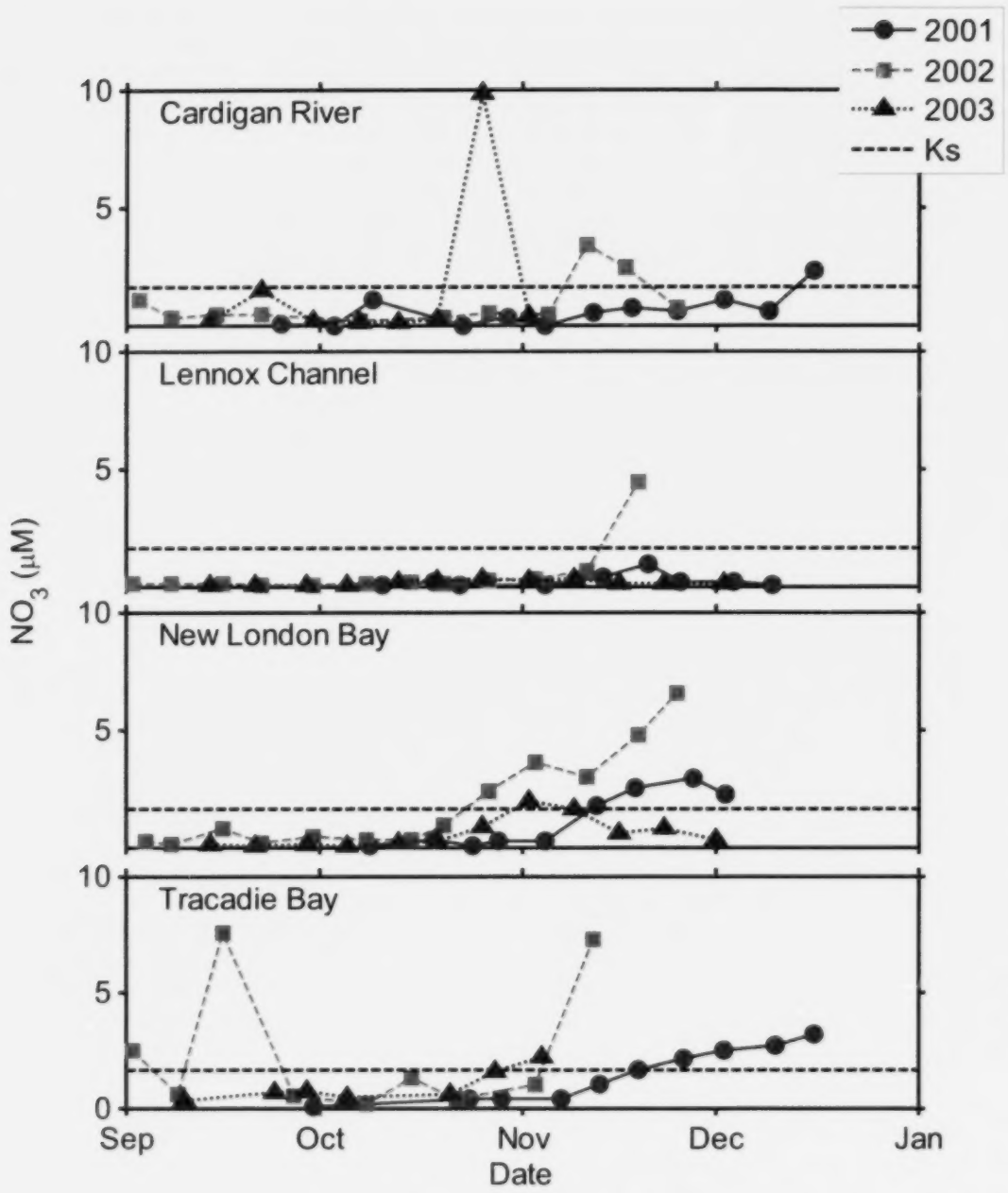

Fig. 6. Nitrate concentrations in four inlets. Horizontal dashed line is the mean Ks value for nitrogen for diatoms from Sarthou *et al.* (2005).

Figure 7 shows some examples of ammonia versus time. Ammonia levels were usually low, and were frequently close to the Ks value for nitrogen. Some small trends were visible: e.g. ammonia levels decreased slightly early in the fall of 2002 in New London Bay, and increased slightly late in the fall in some other inlets, such as Murray River (not shown), but these trends do not necessarily occur every year and are not common to many inlets. Large spikes in ammonia concentration occurred in mid to late fall in many inlets (e.g. Cardigan River, New London Bay, Tracadie Bay) in 2001, but were rare earlier in the season. Only one comparably high level was seen in other years, in Rustico Bay in 2002 (not shown). Smaller elevated ammonia levels, which occurred early in the season, were seen in several inlets in 2002 (e.g. New London Bay).

For most inlets, nitrite concentration versus time plots showed little structure, other than occasional peaks that corresponded with peaks in nitrate. As it did for nitrate, Rustico Bay showed a trend of increasing nitrite late in the season in all three years of the sampling program.

Figure 8 shows some examples of silicate levels. There was a large amount of variation in the seasonal trends for silicate. In a number of inlets, such as Cardigan River, silicate levels were noisy, with levels sometimes lower than the Ks value, sometimes higher. In others, levels were more uniform in a given year, and that level was similar in the different years in some inlets (e.g. New London Bay) or different in others (e.g. St. Marys Bay, not shown).

There is more consistency in the patterns seen for phosphate (Fig. 9) than for the other nutrients. In general, phosphate values decreased slightly from late summer through the fall, and were above the Ks value for diatoms most of the time. The decreasing trend was not monotonic and was sometimes interrupted by extended periods of higher phosphate values (e.g. Cardigan River, 2001). Values below Ks were usually short-lived, although phosphate was less than Ks for approximately a month in Rustico Bay in 2001 (not shown).

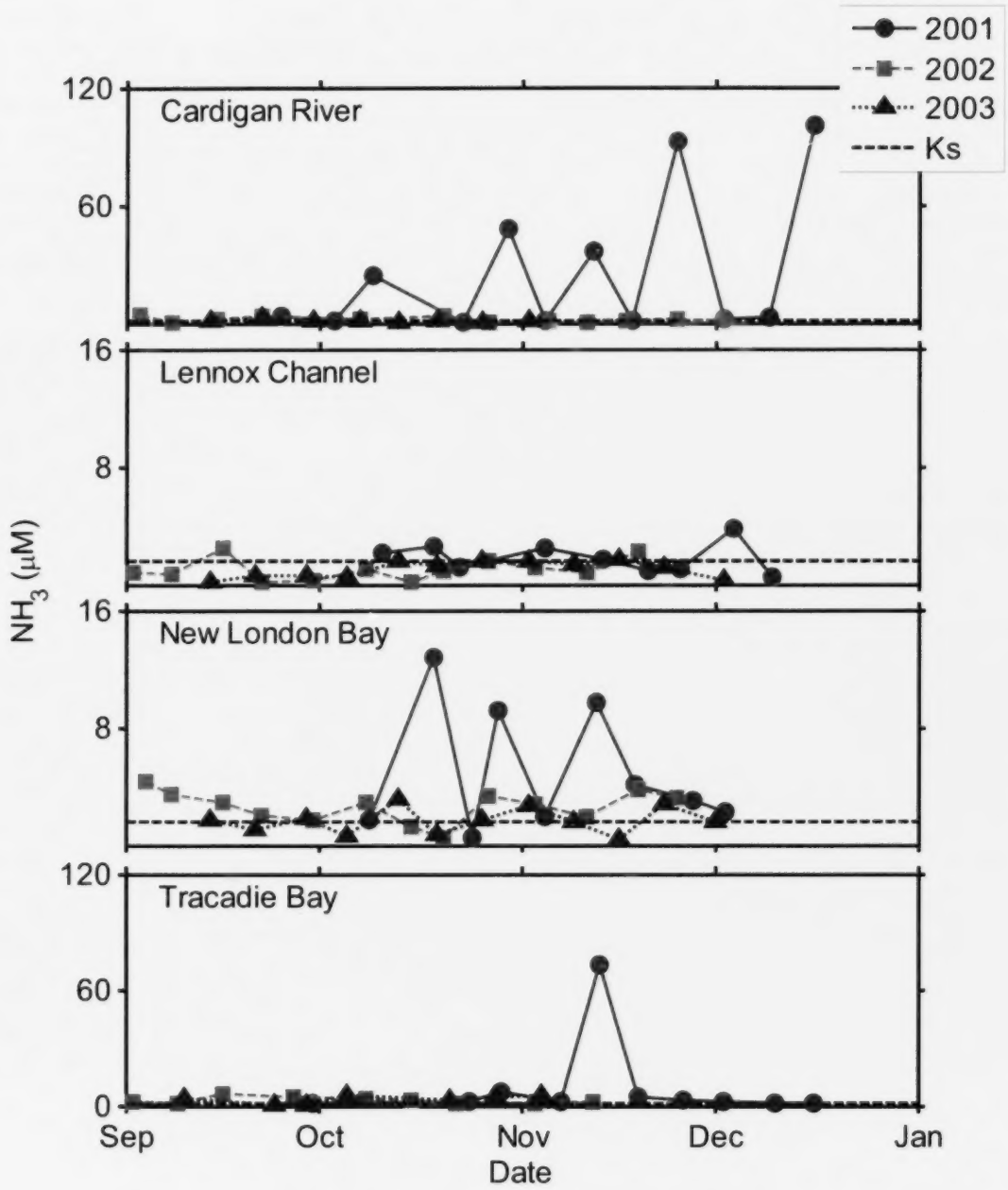

Fig. 7. Ammonia concentrations in four inlets. Horizontal dashed line is the mean Ks value for nitrogen for diatoms from Sarthou *et al.* (2005). Note the different y-axis scales.

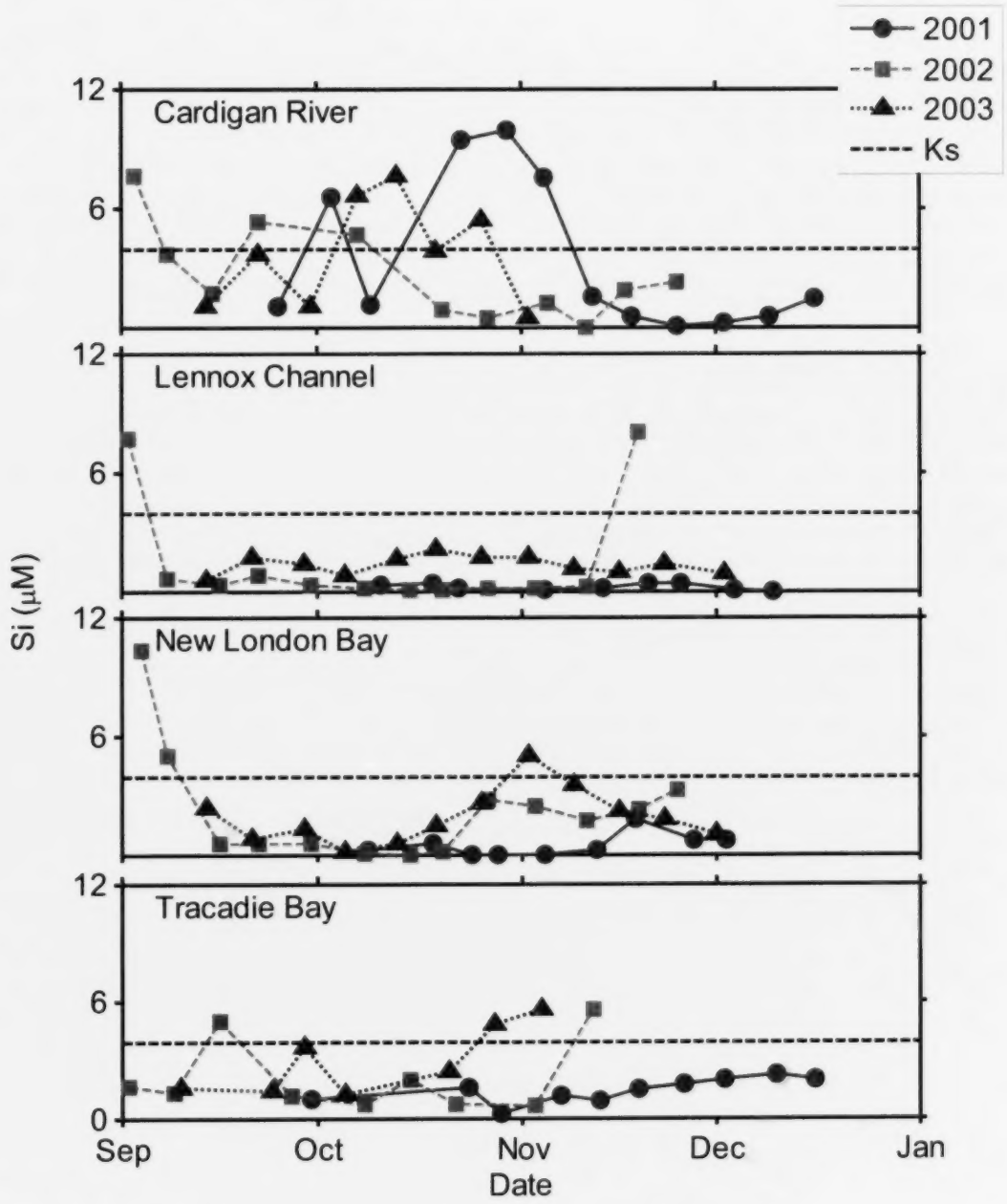

Fig. 8. Silicate concentrations in four inlets. Horizontal dashed line is the mean Ks value for silicate for diatoms from Sarthou *et al.* (2005).

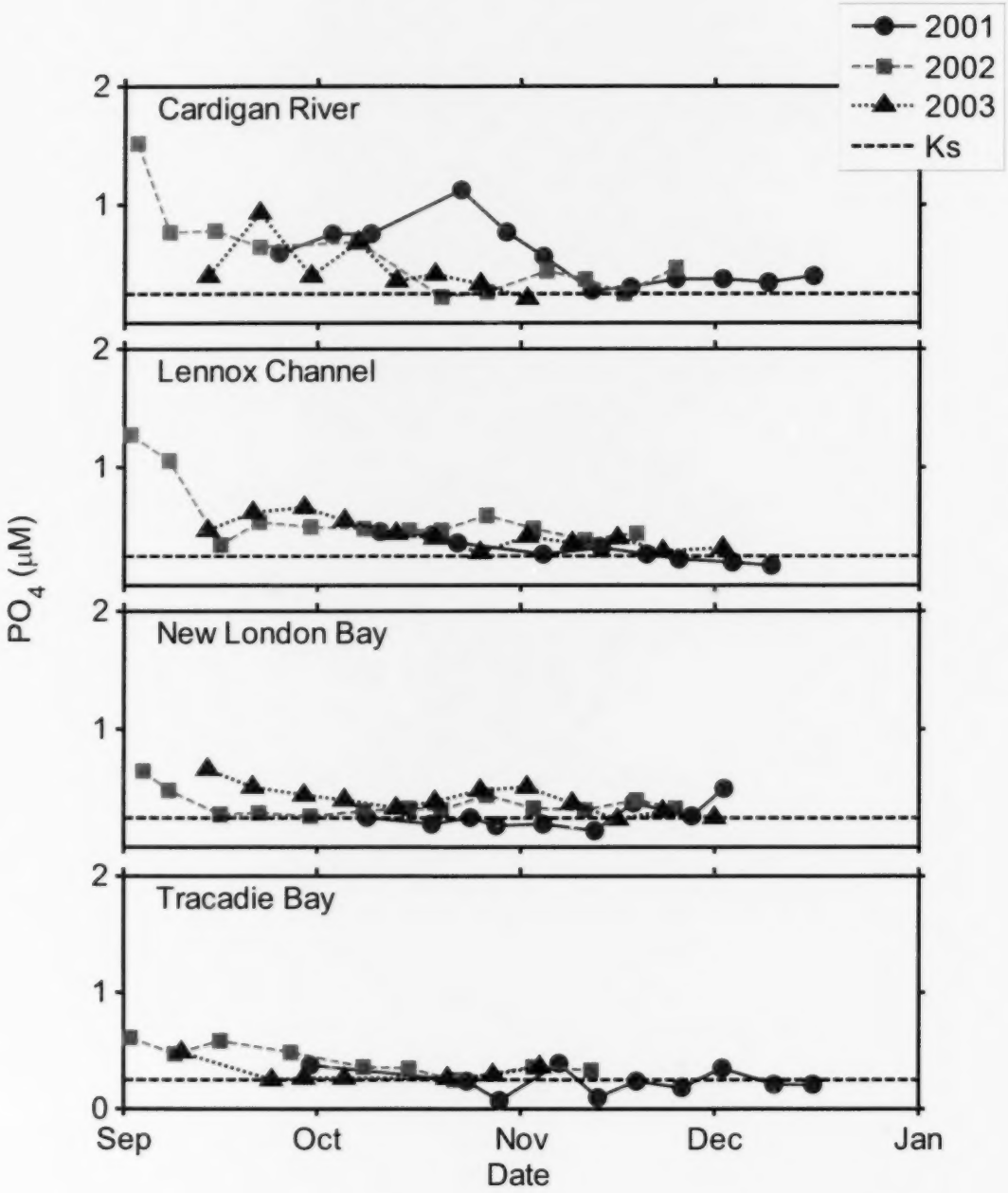

Fig. 9. Phosphate concentrations in four inlets. Horizontal dashed line is the mean Ks value for phosphorus for diatoms from Sarthou *et al.* (2005).

Phytoplankton

A total of 133 phytoplankton samples from four PEI inlets was analyzed for total community composition, in order to obtain detailed time series data during eight to 13 sampling times (Table 6). The total community composition from additional samples was also analyzed, but for fewer dates, from the following inlets: March Water (two samplings in 2001; Appendix D5); Murray River (five samplings in 2002; Appendix E5); and one sampling only in each of Boughton River, Brudenell River, Covehead Bay, Murray River, Rustico Bay, Savage Harbour, St. Marys Bay, and St. Peters Bay (in 2002; Appendix E6, and in 2003; Appendix F6). The concentrations of all of the *Pseudo-nitzschia* species detected, and the presence / absence of the other major species, for the above inlets in 2001, are shown in Appendix D6.

In Cardigan River, there was an increasing trend in total cell number during 2001 to 2003; there was no distinct pattern for the other three inlets (Table 6). Cardigan River also had a 10-fold greater total number of cells than did Tracadie Bay. Lennox Channel and New London Bay had similar, intermediate, numbers of total cells.

Table 6. Total cell counts, averaged over the number of sampling times (mean ± sd), for the four inlets studied in detail, for each of the years 2001–2003.

Inlet	Year	Number of samples	Total cell number for each year (10^6 cells L^{-1})	Total cell number per sampling for each year (10^6 cells L^{-1})	Mean total cell number per sampling for 2001-2003 (10^6 cells L^{-1})	Appendix
Cardigan River	2001	12	23.3	1.94	3.03 ± 0.96	D1
	2002	10	37.9	3.79		E1
	2003	12	40.1	3.34		F1
Lennox Channel	2001	10	6.9	0.69	0.90 ± 0.18	D4
	2002	12	11.9	0.99		E4
	2003	12	12.1	1.01		F4
New London Bay	2001	10	8.9	0.89	0.86 ± 0.18	D3
	2002	13	10.9	0.84		E3
	2003	12	10.4	0.86		F3
Tracadie Bay	2001	10	3.1	0.31	0.29 ± 0.07	D2
	2002	8	1.7	0.22		E2
	2003	12	4.1	0.34		F2

There are 124 apparently distinct species of phytoplankton identified for all inlets studied, during the late summer and fall of 2001 to 2003, including 49 centric diatoms (Bacillariophyceae), 27 pennate diatoms (Bacillariophyceae), 36 Dinophyceae, 3 Dictyochophyceae, 2 Chlorophyceae, 2 Cyanophyceae, 1 Haptophyceae, 1 Chrysophyceae, 1 Euglenophyceae, 1 Litostomatoea, and 1 protist of uncertain taxonomic position (protista *insertae sedis*) (Table 7). There were also unidentified armoured and unarmoured

dinoflagellates, rotifers, tintinids, and other protists. Lists of all the species at each sampling inlet and date are shown in Appendices D-F.

Table 8 shows all of the phytoplankton species whose total concentration (i.e. counts summed over all inlets in all years) was > 100,000 cells L^{-1}, ranked according to cell concentration, for all inlets sampled during 2001 to 2003. Centric diatoms clearly composed the dominant species over these three years, comprising 14 out of these 23 species. Pennate diatoms ranked second (6 out of 23) and dinoflagellates ranked third (3 out of 23). *Skeletonema costatum* (a centric diatom) ranked the highest of all in terms of cell concentration. The abundance of each species was different for each of the three years (see below).

Light micrographs of several species of *Pseudo-nitzschia* and of *Karenia mikimotoi* found in the PEI inlets are shown in Figure 10. In order to identify some species of *Pseudo-nitzschia*, specimens must be examined by electron microscopy. Scanning electron microscopy (SEM) micrographs of several *Pseudo-nitzschia* species found are shown in Figures 11-13. The identification of *P. calliantha* is also based on the presence of a flower-like pattern of 7-8 perforations on the hymen of the poroids (Lundholm *et al.* 2003). These are barely visible using transmitted electron detector (TED) microscopy (Fig. 14), and are best seen with transmission electron microscopy (TEM).

Pseudo-nitzschia species were present in 100% of the samples. Eight species of *Pseudo-nitzschia* were found, based on the cell shape and morphometrics (Table 9). Of these, three are reported for the first time in the Gulf of St. Lawrence: *P. fraudulenta*, *P. americana*, and the tentatively identified *P.* cf. *subpacifica*. The toxigenic *P multiseries* and *P. seriata* were found only in low numbers during this study.

Table 7. Groups of phytoplankton identified for all PEI inlets sampled during the late summer and fall of 2001–2003.

Centric Diatoms	Pennate Diatoms	Dinoflagellates	Other (Class)
Actinoptychus senarius	*Achnanthes* sp.	*Alexandrium pseudogonyaulax*	*Chrysochromulina parkeae* (Haptophyceae)
Attheya decora	*Asterionellopsis glacialis*	*Alexandrium* sp.	*Commation cryoporinum* (Protista *incertae sedis*)
Cerataulina pelagica	*Bacillaria paxillifer*	*Amphidinium carterae*	*Dictyocha fibula* (Dictyochophyceae)
Chaetoceros concavicornis / convolutus	*Cylindrotheca closterium*	*Amphidinium* sp.	*Dictyocha speculum* (Dictyochophyceae)
Chaetoceros convolutus var. *trisetosa*	*Cylindrotheca gracilis*	*Amphidinium sphenoides*	*Dinobryon* spp. (Chrysophyceae)
Chaetoceros contortus [1]	*Entomoneis* sp.	Armoured dinoflagellate	*Ebria tripartita* (Dictyochophyceae)
Chaetoceros danicus	*Grammatophora marina*	*Ceratium fusus*	*Eutreptia / Eutreptiella* (Euglenophyceae)
Chaetoceros debilis	*Gyrosigma balticum*	*Ceratium longipes*	*Merismopedia* sp. (Cyanophyceae)
Chaetoceros decipiens	*Gyrosigma fasciola*	*Dinophysis acuminata*	*Mesodinium rubrum* (Litostomatea)
Chaetoceros diadema	*Gyrosigma littorale*	*Dinophysis norvegica*	*Microcystis* sp. (Cyanophyceae)
Chaetoceros didymus	*Gyrosigma tenuissimum*	*Dinophysis rotundata*	*Pediastrum* sp. (Chlorophyceae)
Chaetoceros didymus var. *protuberans*	*Lennoxia* sp.	*Dinophysis* sp.	*Staurastrum* sp. (Chlorophyceae)
Chaetoceros ingolfianus	*Licmophora abbreviata*	*Gonyaulax spinifera*	
Chaetoceros laciniosus	*Navicula* sp.	*Gonyaulax* spp.	
Chaetoceros lauderi / teres	*Pleurosigma / Gyrosigma*	*Gymnodinium splendens* [5]	
Chaetoceros lorenzianus	*Pleurosigma angulatum*	*Gyrodinium spirale*	
Chaetoceros radicans	*Pseudo-nitzschia americana*	*Gyrodinium* spp.	
Chaetoceros similis	*Pseudo-nitzschia delicatissima*	*Heterocapsa* sp.	
Chaetoceros simplex	*Pseudo-nitzschia calliantha*	*Heterocapsa triquetra*	
Chaetoceros socialis	*Pseudo-nitzschia pungens*	*Karenia mikimotoi* [6, 7]	
Chaetoceros spp.	*Pseudo-nitzschia multiseries*	*Phalacroma* sp.	
Chaetoceros subtilis	*Pseudo-nitzschia seriata*	*Polykrikos* cf. *kofoidii*	
Chaetoceros teres	*Pseudo-nitzschia fraudulenta*	*Preperidinium meunieri*	
Corethron criophilum [2]	*Pseudo-nitzschia* cf. *subpacifica* [4]	*Prorocentrum micans* [8]	
Coscinodiscus spp.	*Rhabdonema* sp.	*Prorocentrum micans* [9]	
Cyclotella sp.	*Striatella unipunctata*	*Prorocentrum minimum*	
Dactyliosolen fragilissimus	*Thalassionema nitzschioides*	*Prorocentrum* spp.	
Detonula confervacea		*Protoperidinium* spp.	
Guinardia delicatula		*Protoperidinium bipes* [10]	
		Protoperidinium conicum	
		Protoperidinium punctulatum / subinerme	

Centric Diatoms	Pennate Diatoms	Dinoflagellates	Other (Class)
Guinardia flaccida		*Protoperidinium* cf. *conicum*	
Guinardia striata		*Pyrocystis lunata*	
Leptocylindrus danicus		*Scrippsiella* sp.	
Leptocylindrus mediterraneus		*Scrippsiella trochoidea*	
Leptocylindrus minimus		Unarmoured dinoflagellate	
Melosira monoliformis [3]			
Melosira spp.			
Odontella aurita			
Paralia marina			
Proboscia alata			
Rhizosolenia hebetata var. *hebetata*			
Rhizosolenia hebetata var. *semispina*			
Rhizosolenia imbricata			
Rhizosolenia pungens			
Rhizosolenia setigera			
Rhizosolenia spp.			
Skeletonema costatum			
Thalassiosira auguste-lineata			
Thalassiosira nordenskioeldii			
Thalassiosira spp.			

[1] *Chaetoceros contortus* previously known as *Chaetoceros compressus*
[2] *Corethron criophilum* = *Corethron hystrix*
[3] *Melosira monoliformis* is also spelled as *Melosira moniliformis*
[4] Tentative identification of *Pseudo-nitzschia* cf. *subpacifica*, based on light microscopy only
[5] *Gymnodinium splendens* = *Gymnodinium sanguineum* = *Akashiwo sanguinea*
[6] Identification of *Karenia mikimotoi* by Dr. Gert Hansen (Biological Institute, Copenhagen, Denmark)
[7] *Karenia mikimotoi* = *Gymnodinium mikimotoi* = *Gymnodinium nagasakiense* = *Gyrodinium aureolum*
[8] Similar in shape to that described in Bérard-Therriault *et al.* (1999), Plates 63a and 63b
[9] Similar in shape to that described by Horner (2002; p. 112), and observed in the Bay of Fundy (M. LeGresley, pers. comm.)
[10] *Protoperidinium bipes* in Bérard-Therriault *et al.* (1999) = *Minuscula bipes*

Table 8. Phytoplankton species with total cell concentrations > 100,000 cells L^{-1} (summed over all inlets in all years), for all PEI inlets sampled.

Species	Type	Total (Cells L^{-1})
Skeletonema costatum	Centric diatom	109,165,891
Pseudo-nitzschia calliantha	Pennate diatom	53,508,536
Pseudo-nitzschia delicatissima	Pennate diatom	9,487,229
Karenia mikimotoi	Dinoflagellate	7,465,361
Chaetoceros spp.	Centric diatom	4,818,529
Pseudo-nitzschia pungens / multiseries	Pennate diatoms	2,881,851
Guinardia delicatula	Centric diatom	2,522,918
Chaetoceros contortus	Centric diatom	1,815,943
Cerataulina pelagica	Centric diatom	1,597,406
Thalassiosira nordenskioeldii	Centric diatom	1,093,712
Dactyliosolen fragilissimus	Centric diatom	1,081,251
Leptocylindrus minimus	Centric diatom	1,053,558
Thalassionema nitzschioides	Pennate diatom	491,215
Cylindrotheca closterium	Pennate diatom	472,758
Prorocentrum minimum	Dinoflagellate	338,651
Chaetoceros debilis	Centric diatom	299,355
Chaetoceros socialis	Centric diatom	249,338
Thalassiosira spp.	Centric diatom	210,571
Asterionellopsis glacialis	Centric diatom	190,321
Rhizosolenia hebetata var. *semispina*	Centric diatom	122,652
Leptocylindrus danicus	Centric diatom	116,564
Chaetoceros lorenzianus	Centric diatom	111,151

Table 9. Morphometrics of *Pseudo-nitzschia* species identified from PEI inlets. The values are only a guideline, because only one "representative" valve was measured for each species, after examining at least 30 valves. Identifications of *P.* cf. *subpacifica* and *P. americana* are based only on cell shape and size, as seen by light microscopy (see Table 3); the other morphometrics were obtained by scanning electron microscopy.

***Pseudo-nitzschia* Species**	**Length (µm)**	**Width (µm)**	**Central interspace**	**Striae per 10 µm**	**Fibulae per 10 µm**	**Poroids per 1 µm**	**Figure**
P. pungens	129.0	3.60	No	10	10	3	11A, B
P. multiseries	86.3	3.62	No	13	13	6	11C, D
P. seriata	144.0	6.01	No	19	16	8	11E, F
P. calliantha	82.9	1.64	Yes	39	24	5	12A, B
P. delicatissima	40.2	1.71	Yes	39	27	9	12C, D
P. fraudulenta	95.3	6.10	Yes	24	24	5	13A-D
P. cf. *subpacifica*	~88	~7	-	-	-	-	-
P. americana	12-39	2.5-3.7	-	-	-	-	-

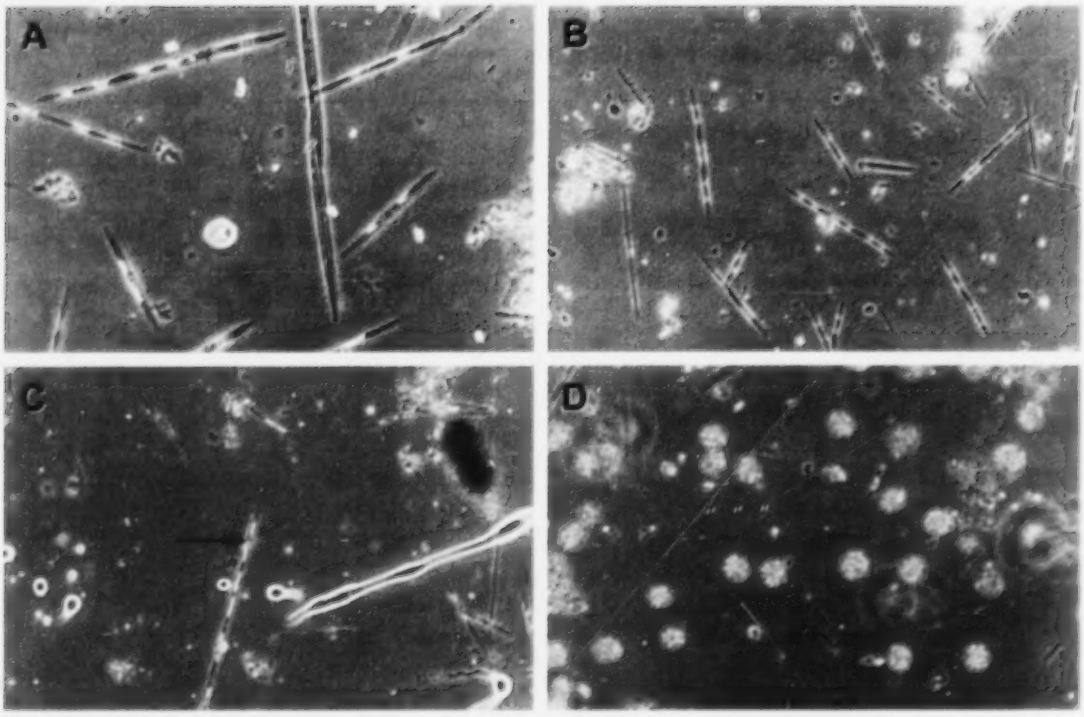

Fig. 10. Light micrographs of formalin-acetic-acid-preserved phytoplankton from PEI (photomicrographs by M. LeGresley; DFO, St. Andrews Biological Station).

A) Mixture of several *Pseudo-nitzschia* species; Cardigan River (17-Dec-01); magnification: 40X with 10X ocular.

B) Chains of *Pseudo-nitzschia calliantha*; Cardigan River (17-Dec-01); magnification: 20X with 10X ocular.

C) Chain of *Pseudo-nitzschia fraudulenta* (arrow); Lennox Channel (14-Nov-01); magnification: 20X with 10X ocular.

D) Round cells, tentatively identified as *Karenia mikimotoi*; Cardigan River (31-Oct-01); magnification: 20X with 10X ocular.

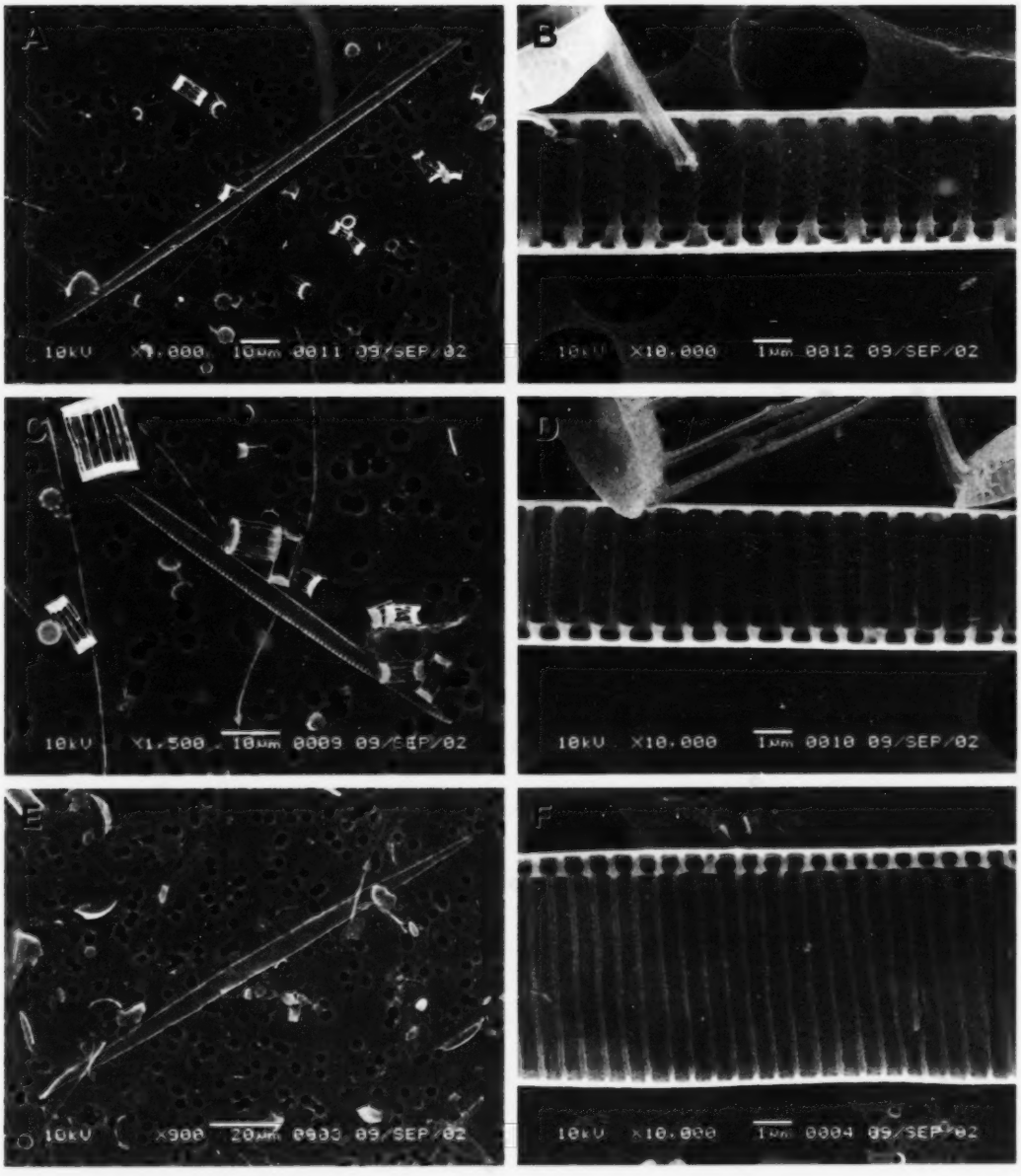

Fig. 11. SEMs of the inside valves of *Pseudo-nitzschia* spp. from Cardigan River, PEI; 4-Sep-02. Images on the right are a higher magnification of those on the left. Note the absence of a central interspace (photomicrographs by J. Ehrman; Digital Microscopy Facility).

A) *P. pungens*, whole valve, showing linear lanceolate valve shape.
B) *P. pungens*, central part of valve, showing two rows of large poroids per striae.
C) *P. multiseries*, whole valve, showing linear lanceolate valve shape.
D) *P. multiseries*, central part of valve, showing four rows of small poroids per striae.
E) *P. seriata*, whole valve, showing asymmetrical, wide valve shape.
F) *P. seriata*, central part of valve, showing 3-4 rows of minute poroids per striae.

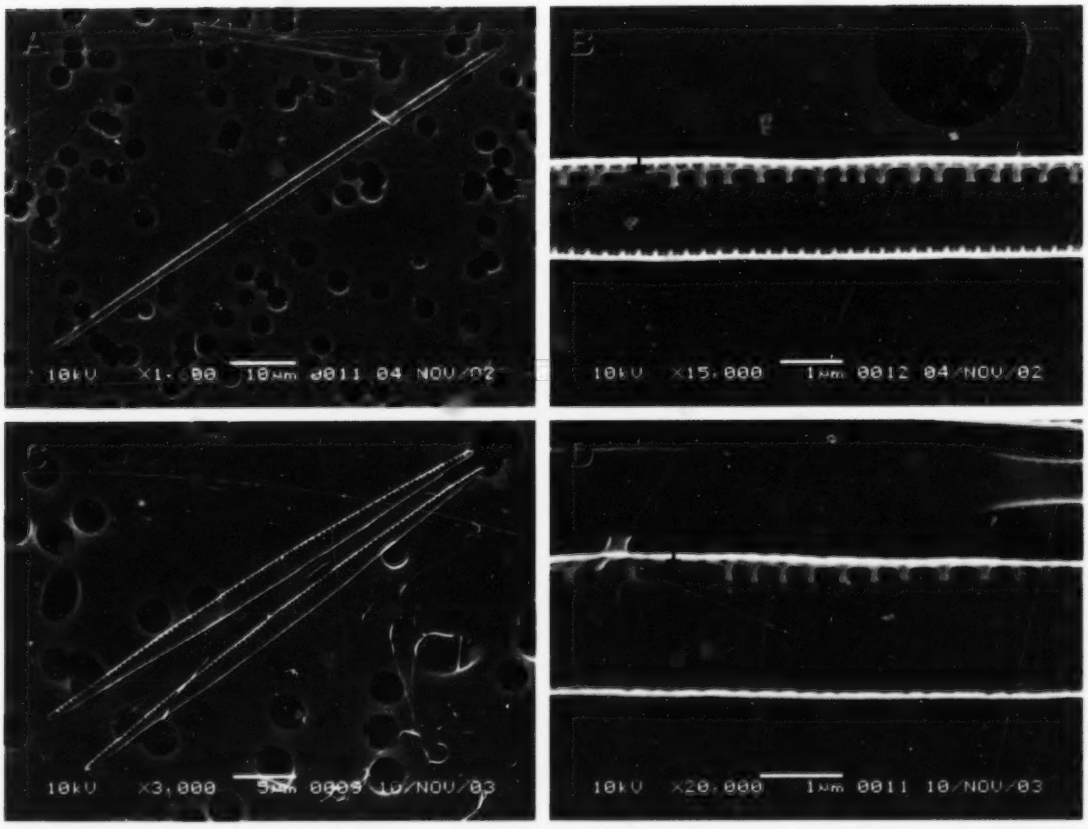

Fig. 12. SEMs of the inside valves of *Pseudo-nitzschia* spp. from Lennox Channel (Malpeque Bay), PEI. Images on the right are a higher magnification view of those on the left. Note the presence of a central interspace (arrows) on each of these valves (photomicrographs by J. Ehrman; Digital Microscopy Facility).

A) *P. calliantha*, whole valve, showing narrow valve shape; 28-Oct-02.

B) *P. calliantha*, central part of valve, showing one row of square poroids, with barely visible perforations arranged in a circle; 28-Oct-02.

C) *P. delicatissima*, whole valves of the same cell, showing narrow valve shape; 3-Nov-03.

D) *P. delicatissima*, central part of valve, showing two rows of minute poroids; 3-Nov-03.

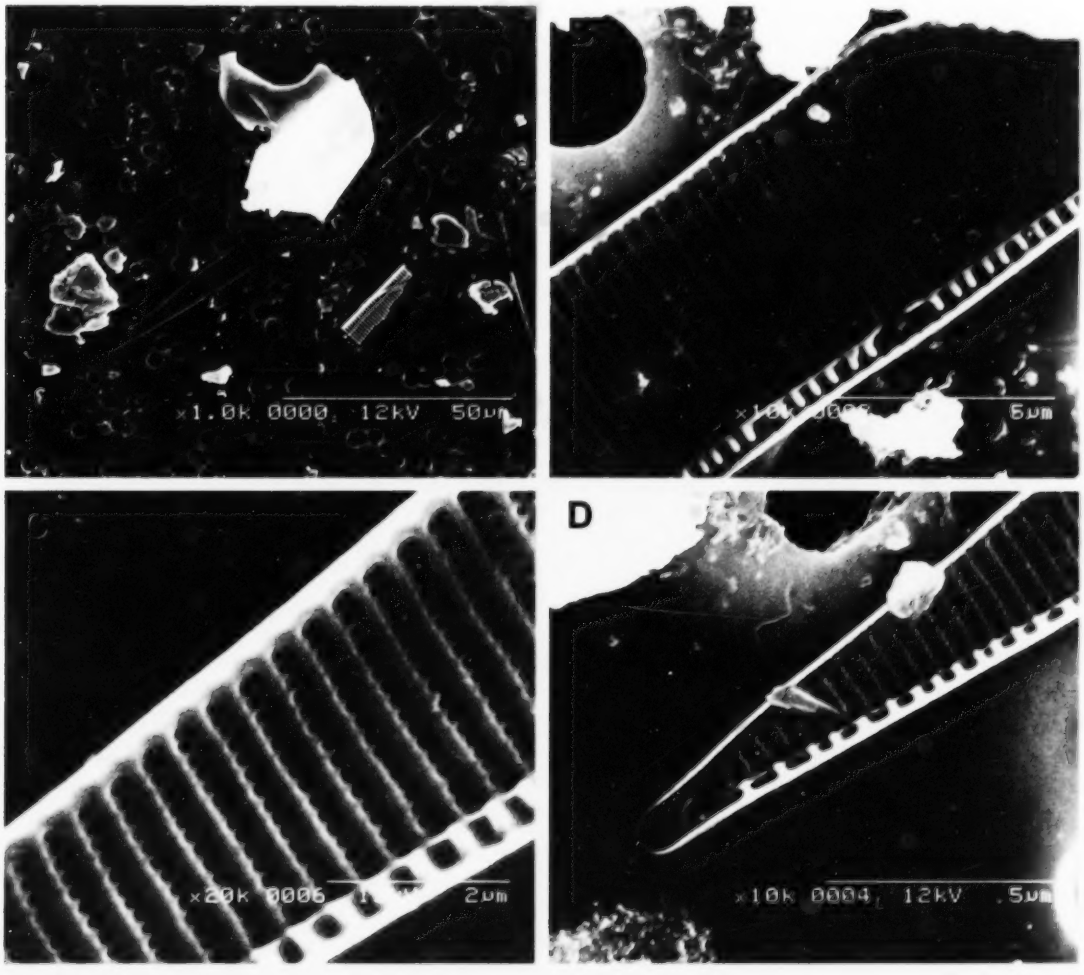

Fig. 13. SEMs of the inside valves of *Pseudo-nitzschia fraudulenta* from New London Bay, PEI; 3-Dec-01 (photomicrographs by M. LeGresley; St. Andrews Biological Station).

A) Whole valve, showing lanceolate outline of the wide valve.
B) Central part of valve, showing the presence of a central interspace (bottom right).
C) Region away from the central part of valve, showing two rows of small poroids per striae; poroids are in alternating arrangement.
D) Valve apex, showing end of raphe, poroids and striae.

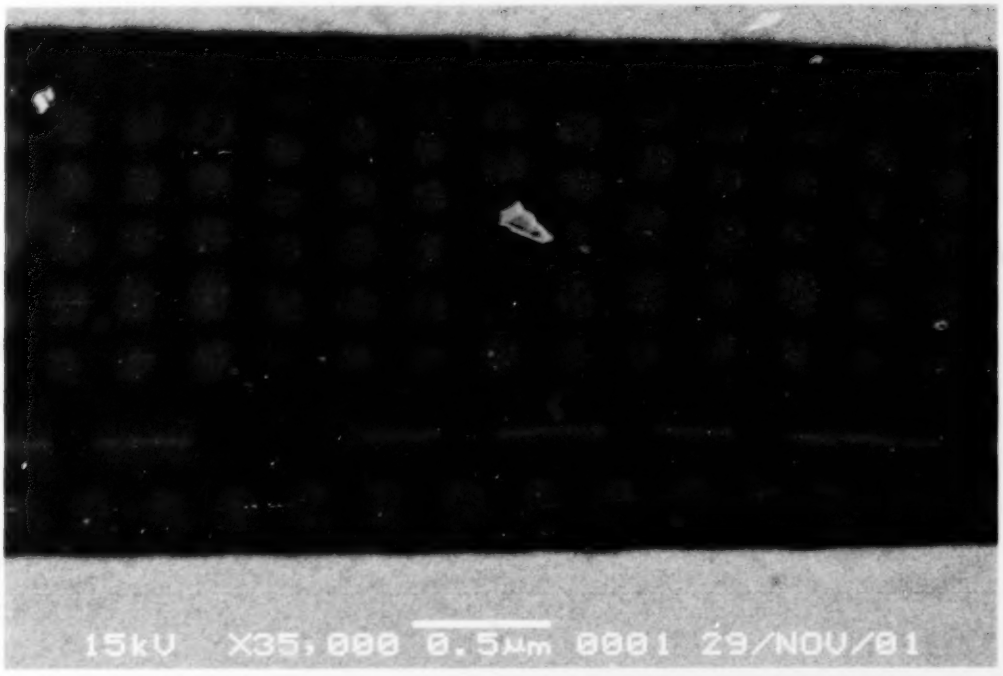

Fig. 14. SEM transmitted electron detector (TED) micrograph of *Pseudo-nitzschia calliantha* from Brudenell River, Prince Edward Island; 5-Nov-01 (photomicrograph by J. Ehrman; Digital Microscopy Facility). In this TED image, which simulates transmission electron microscopy (TEM), the characteristic circular pattern of flower-like perforations on the hymen of the large poroids is barely visible.

Figures 15-19 show the changes in cell concentration of the five most abundant phytoplankton species (excluding *Chaetoceros* spp.; see Table 8) during the late summer to fall periods of 2001–2003, in the four inlets for which phytoplankton data were collected in more detail. The centric diatom *Skeletonema costatum* was most abundant, and generally peaked in late September to early October (Fig. 15). Cardigan River showed the highest concentrations of *S. costatum*, reaching a maximum (7.76×10^6 cells L^{-1}) on 16-Sep-02 (Appendix E1). Cell concentrations remained generally elevated during most of the 2003 sampling period. In 2001, concentrations were considerably lower in Cardigan River, but an earlier peak may have been missed because of a late start in sampling (26-Sep-01). Populations of *S. costatum* were the lowest in Tracadie Bay, during all three years (Fig. 15).

The second most abundant phytoplankton species during the three years, and the most abundant species of *Pseudo-nitzschia*, was the non-toxic pennate diatom *P. calliantha* (Table 8). It was found most abundantly in Cardigan River, where in 2002 it was still increasing (at 5.33×10^6 cells L^{-1}) when sampling stopped on 18-Nov-02 (Fig. 16). In 2001 in Cardigan River, the cell concentration was highest (2.15×10^6 cells L^{-1}) on 3-Dec-01 (Appendix D1). Cell concentrations were substantially lower in 2003, never exceeding 2.54×10^4 cells L^{-1} (Cardigan River), and were generally an order of magnitude less than that (Appendix F1).

The non-toxic pennate diatom *Pseudo-nitzschia delicatissima* was the third highest in abundance (Table 8). It was present in significant numbers only in 2001, in all four inlets studied, and was virtually undetectable in 2002 and 2003 (Fig. 17). Highest concentrations were reached in Cardigan River (2.19 x 10^6 cells L^{-1}) on 19-Nov-01 (Appendix D1). The lowest concentrations were in Tracadie Bay (maximum of 8,670 cells L^{-1}, on 8-Nov-01; Appendix D2). Sampling in Lennox Channel did not start until 11-Oct-01, and it is possible that the peak in the bloom was missed because cell numbers decreased after that sampling date. However, in New London Bay, the bloom's maximum occurred later in the fall (5-Nov-01). Indeed, each inlet had a substantially different pattern of *P. delicatissima* cell growth.

Within the species of *Pseudo-nitzschia*, the group *P. pungens / P. multiseries* was the next highest in abundance, but sixth highest relative to all of the phytoplankton (Table 8). Again, each year showed a different pattern of abundance (Fig. 18). In 2001, there was a moderate bloom in Cardigan River, reaching 5.51 x 10^5 cells L^{-1} on 10-Oct-01 (Appendix D1). In 2002, a smaller bloom occurred in New London Bay, reaching 2.36 x 10^5 cells L^{-1} on 17-Sep-02 (Appendix E3). In 2003, the peak bloom was in Lennox Channel, reaching 2.06 x 10^5 cells L^{-1} on 24-Nov-03 (Appendix F4). As with the other phytoplankton, concentrations of *P. pungens / P. multiseries* were lowest in Tracadie Bay, reaching only a maximum of 580 cells L^{-1} on 29-Oct-29 (Appendix F2).

Because light microscopy cannot distinguish between the non-toxic *P. pungens* and the toxic *P. multiseries*, these species were grouped together in the cell counts shown. Scanning electron microscopy (SEM) carried out on selected samples (but not necessarily from the peaks in blooms) later revealed the proportion of each species of *Pseudo-nitzschia* (Table 10). Although only a few samples were examined by SEM, it is still evident that the toxin-producing *P. multiseries* was found only in low proportions, and most samples contained no such valves. This explains why no DA-contaminated mussels were detected during 2001–2003. The high numbers of non-toxic *P. calliantha* were not a threat to the aquaculture industry during that period.

Pseudo-nitzschia americana was found only in 2003, and in low numbers (maximum of 5,780 cells L^{-1} in Lennox Channel, on 30-Sep-03), but in each of the four inlets (Appendix D-F). *Pseudo-nitzschia* cf. *subpacifica* was the least abundant *Pseudo-nitzschia* species, found only on two occasions and in two inlets: 578 cells L^{-1} in New London Bay, on 17-Nov-01 (Appendix F3); and 1,156 cells L^{-1} in Lennox Channel, also on 17-Nov-03 (Appendix F4).

The potentially toxic dinoflagellate *Karenia mikimotoi* was the fourth most abundant phytoplankter (Table 8). It was found in substantial numbers only in Cardigan River, and only in 2001 and 2003 (Fig. 19). In 2001, peak numbers reached 1.54 x 10^6 cells L^{-1} on 31-Oct-01 (Appendix D1). In 2003, the peak was at 1.33 x 10^6 cells L^{-1} on 20-Oct-03 (Appendix F1). In 2002, *K. mikimotoi* was detected on only one occasion, at 480 cells L^{-1} on 23-Sep-02 (Appendix D1). On the north shore of PEI, it was present at only low concentrations in Lennox Channel (maximum of 3,468 cells L^{-1} on 20-Oct-03), New London Bay (maximum of 16,762 cells L^{-1} on 6-Oct-03), and Tracadie Bay (maximum of 2,720 cells L^{-1} on 25 Oct-01).

A group of unidentified centric diatom species of the genus *Chaetoceros* made up the fifth most abundant phytoplankton. They were found at all inlets, in all years, but were most

abundant in 2003 (6.96 x 10^5 cells L^{-1}, on 6-Oct-03, in Lennox Channel; Appendix F4). This abundant group of *Chaetoceros* spp. is thought to have been responsible for maintaining high mussel meat yields during 2003 (Smith 2003). No other descriptive information is available for these *Chaetoceros* spp.

Table 10. Proportion of *Pseudo-nitzschia* species at selected inlets and dates, as determined by scanning electron microscopy. Total counts were obtained by light microscopy (LM), and *P. pungens* was grouped with *P. multiseries*, because of the inability to distinguish the two with LM.

Inlet	Date	Species	Proportion (%)	Total count (cells L^{-1})
Cardigan River	13-Nov-01	*P. calliantha*	98	1,703,400
		P. pungens	2	2,360
		P. multiseries	0	
Cardigan River	10-Dec-01	*P. calliantha*	99	1,862,050
		P. pungens	1	1,920
		P. multiseries	0	
New London Bay	9-Oct-01	*P. calliantha*	51	44,312
		P. pungens	39	22,348
		P. multiseries	10	
New London Bay	5-Nov-01	*P. calliantha*	99	534,400
		P. pungens	1	5,964
		P. multiseries	0	
New London Bay	3-Dec-01	*P. calliantha*	95	525,980
		P. pungens	3	1,200
		P. multiseries	0	
		P. fraudulenta	2	500
Lennox Channel	11-Oct-01	*P. calliantha*	94	233,800
		P. pungens	5	16,925
		P. multiseries	1	
New London Bay	17-Sep-02	*P. calliantha*	6	13,294
		P. pungens	94	236,402
		P. multiseries	0	
New London Bay	20-Nov-02	*P. calliantha*	94	158,950
		P. pungens	6	400
		P. multiseries	0	
Lennox Channel	1-Oct-02	*P. calliantha*	98	1,269,200
		P. pungens	1	23,400
		P. multiseries	1	

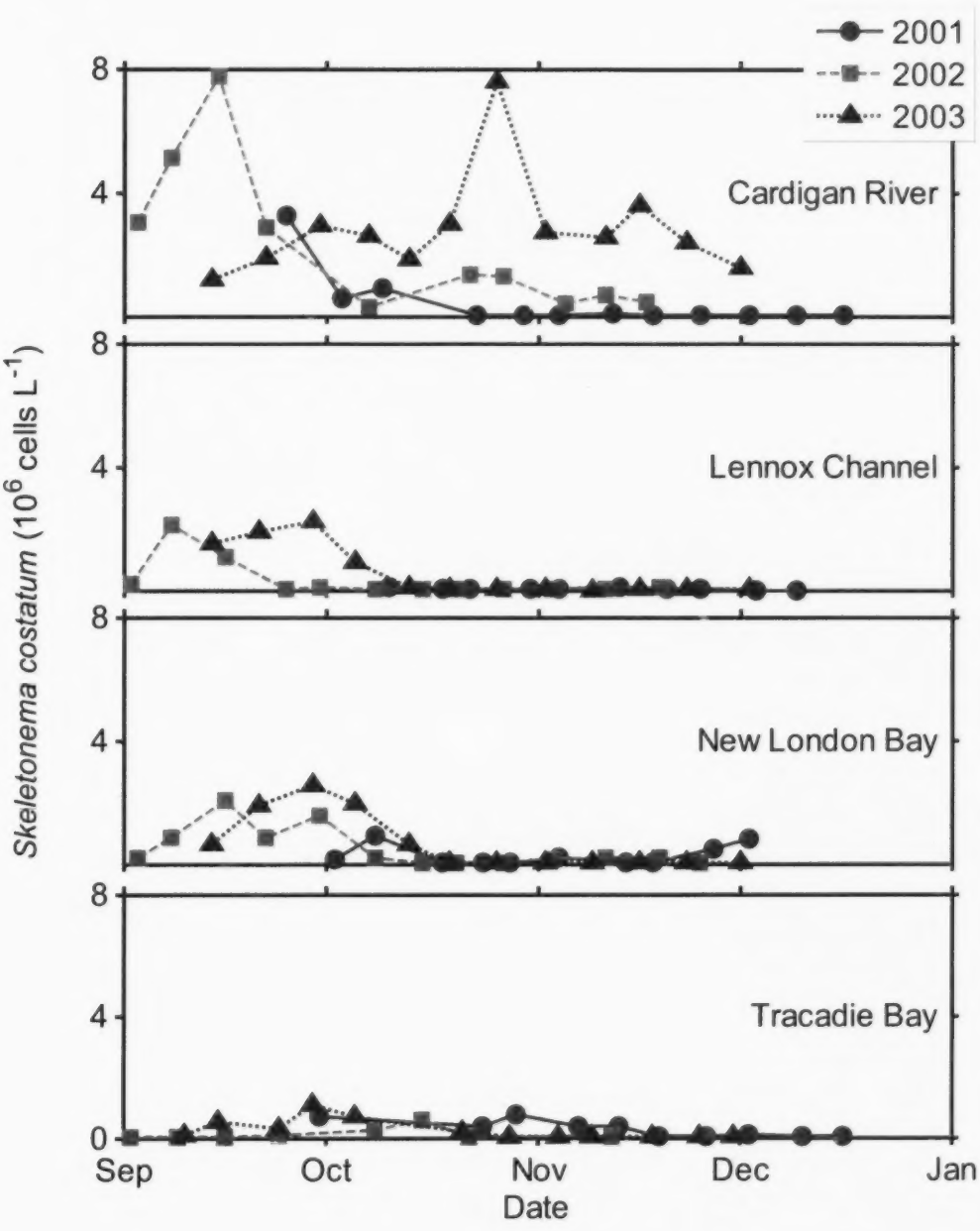

Fig. 15. Concentrations of the centric diatom *Skeletonema costatum* in four inlets of PEI, during the late summer and fall of 2001–2003.

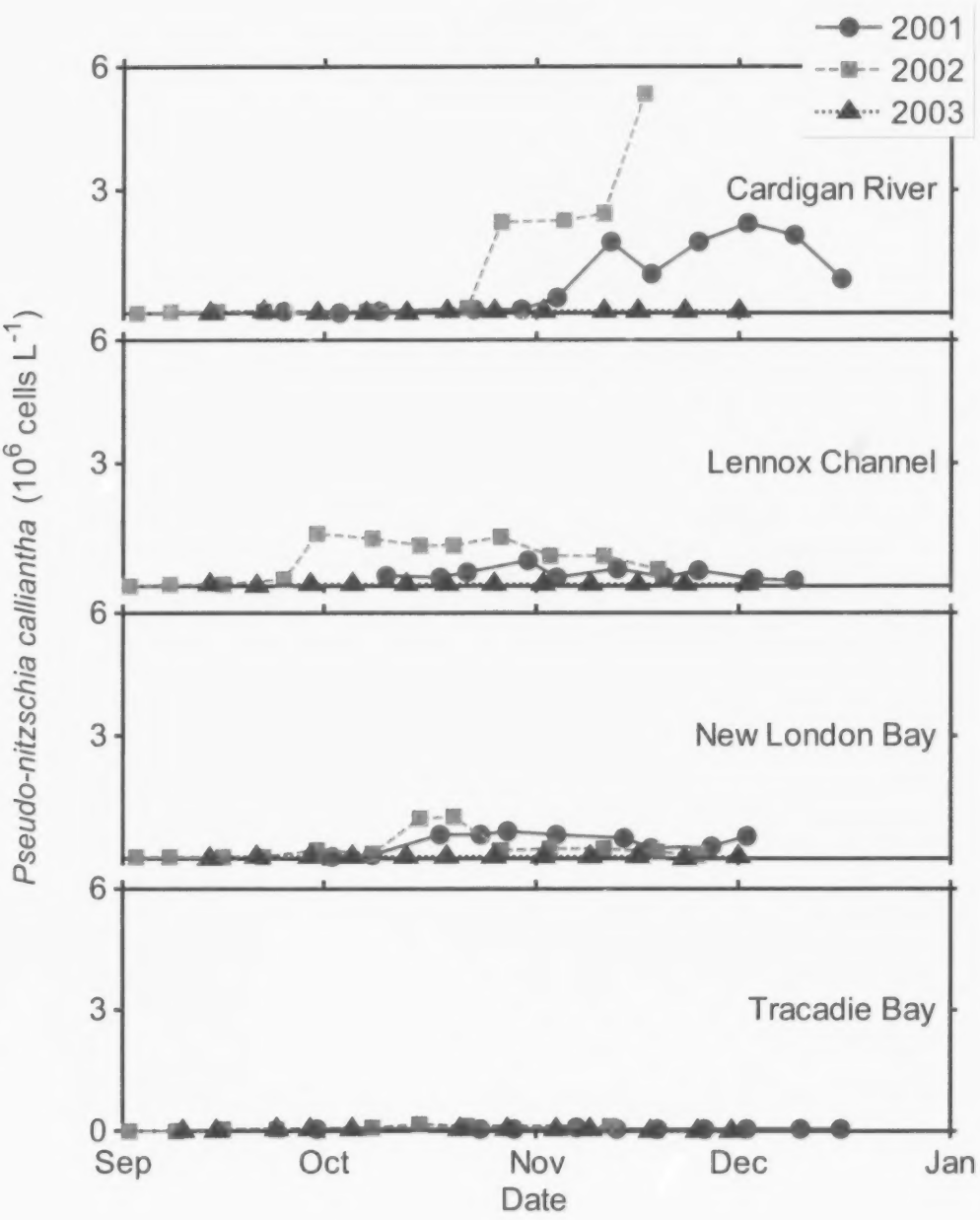

Fig. 16. Concentrations of the non-toxic pennate diatom *Pseudo-nitzschia calliantha* in four inlets of PEI, during the late summer and fall of 2001–2003.

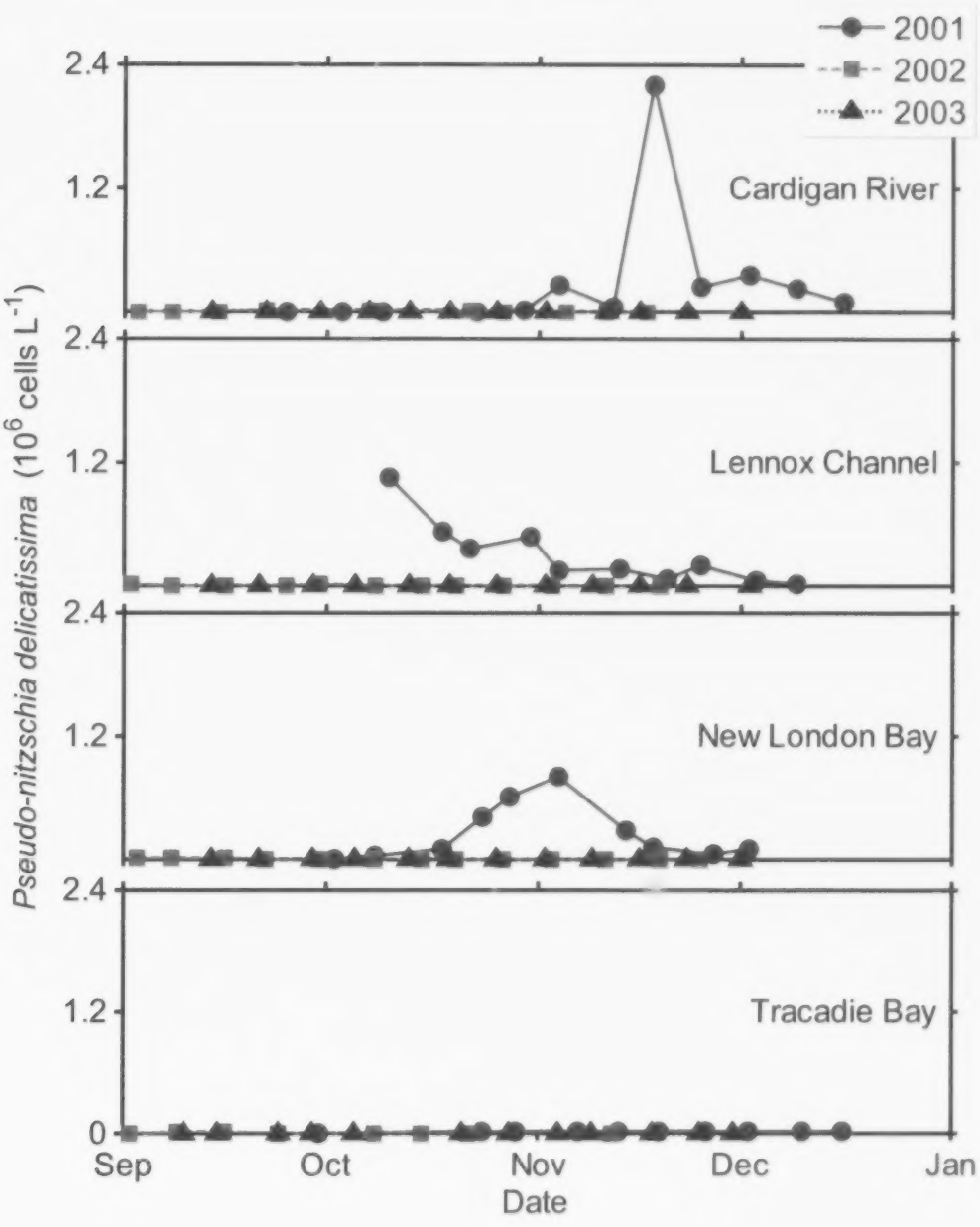

Fig. 17. Concentrations of the non-toxic pennate diatom *Pseudo-nitzschia delicatissima* in four inlets of PEI, during the late summer and fall of 2001–2003.

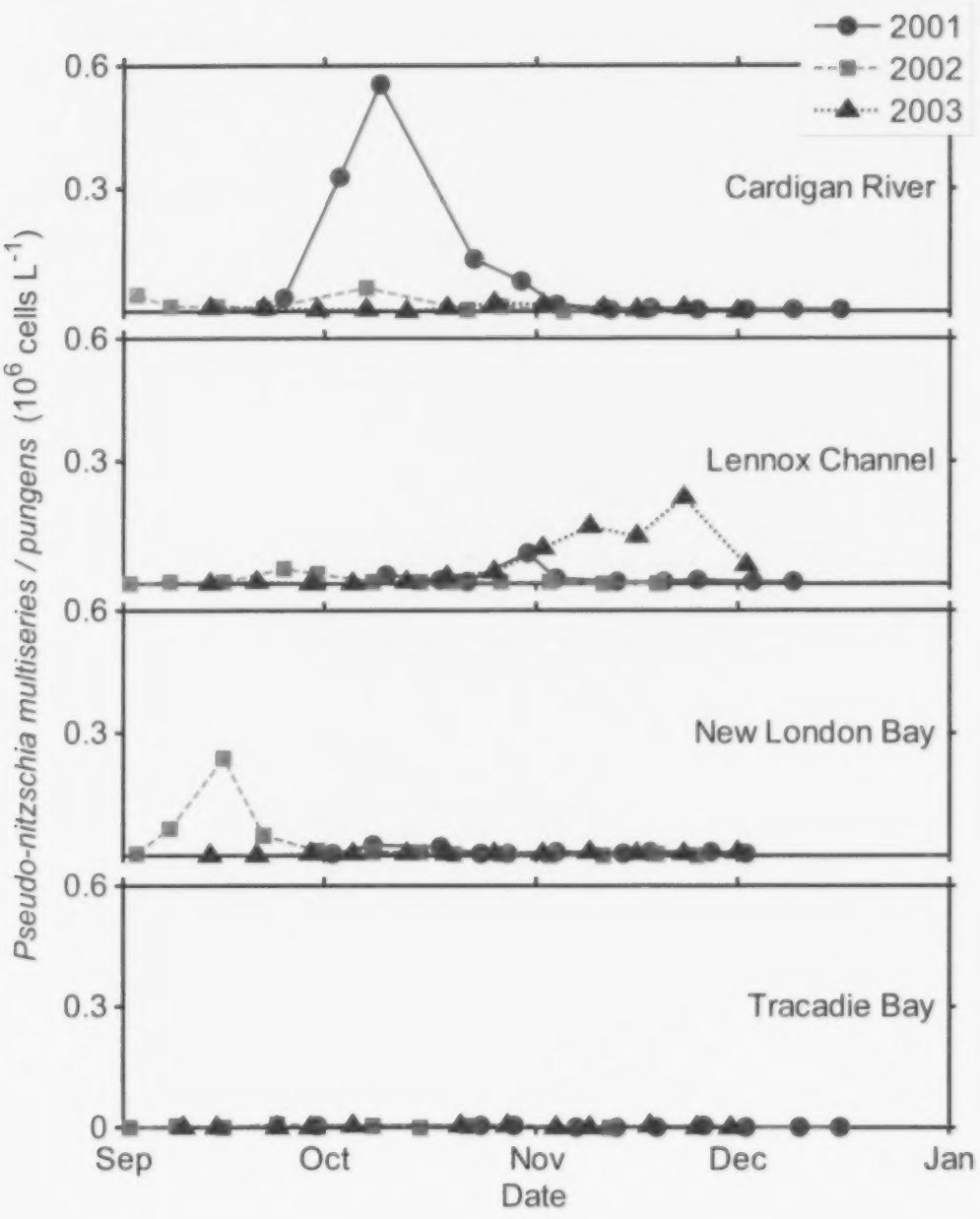

Fig. 18. Concentrations of the non-toxic *Pseudo-nitzschia pungens* plus the toxic *Pseudo-nitzschia multiseries* in four inlets of PEI, during the late summer and fall of 2001–2003. *Pseudo-nitzschia pungens* and *P. multiseries* cannot be distinguished using light microscopy; scanning electron microscopy was later used to determine the relative abundance of the two species (see Table 10).

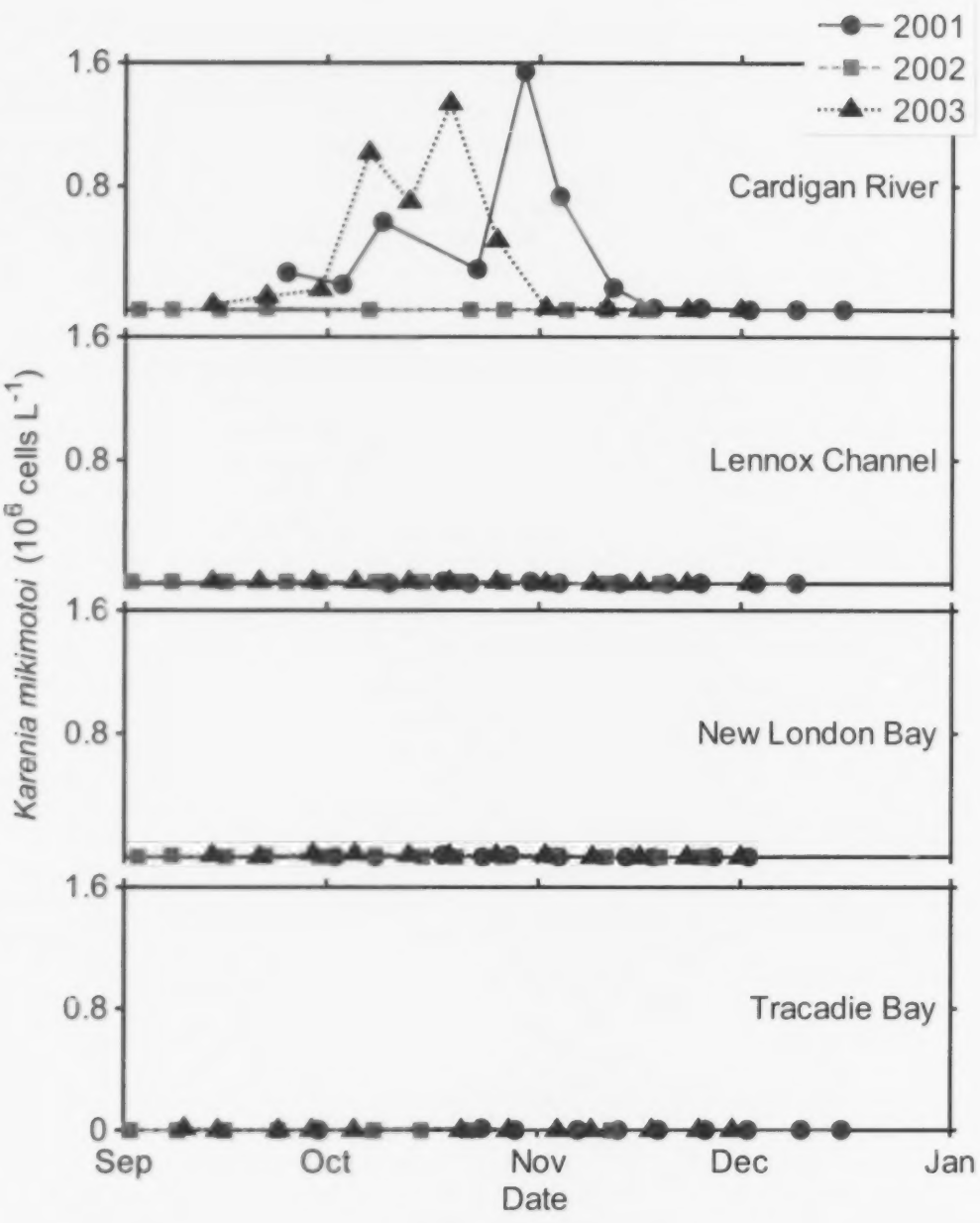

Fig. 19. Concentrations of the potentially toxic dinoflagellate *Karenia mikimotoi* in four inlets of PEI, during the late summer and fall of 2001–2003.

DISCUSSION

Nutrient Limitation

Although the factors that control the abundance and species composition of phytoplankton have been major preoccupations of biological oceanography since its inception, important aspects of how such controls function and interact are still controversial and actively studied (de Baar 1994; Arrigo 2005). As de Baar (1994) notes in his review, considerable debate has occurred about the applicability of Liebig's "Law of the Minimum" to phytoplankton communities, but one unequivocal conclusion is that the nutrient that is least abundant compared to requirements limits the ultimate biomass of the phytoplankton or, in other words, determines the carrying capacity of the system. Although it is important to distinguish between how factors influence carrying capacity, and how they influence growth rates, clearly growth rates will determine whether the phytoplankton community can approach its carrying capacity before other factors, such as grazing pressure, light limitation, advection and sinking, become important. Some authors refer to carrying capacity limitation as biomass limitation, but this may cause confusion between the ultimate biomass available (i.e. carrying capacity) versus that which is attainable given growth-limiting factors (i.e. ambient biomass). To avoid this potential confusion, we will use the term carrying capacity. The actual ambient biomass will depend on the relative rates of production and loss of phytoplankton.

As de Baar (1994) notes, only one nutrient (the "most limiting") can limit carrying capacity, but many can limit growth rates. The lack of recognition that these two types of limitation are fundamentally different has led to much confusion in the literature. Concepts discussed are rarely explained carefully. Carrying capacity and growth limitation measures are sometimes both used in the same criteria for determining limitation, without explicitly recognizing that two types of limitation are being combined into one index (e.g. Dortch and Whitledge 1992).

Many studies have found a saturating relationship between nutrient uptake rate and nutrient concentration, which, as noted in the Introduction, is usually expressed by the Michaelis-Menten equation:

$$V = V_{max} * \frac{[Nut]}{[Nut] + Ks} \qquad (1)$$

When [Nut] is >> Ks, $V \sim V_{max}$, and the nutrient is not limiting. But when [Nut] ~ Ks, $V < V_{max}$, and the V versus [Nut] curve has the classic hyperbolic shape. Many culture experiments have confirmed the shape of this relationship for individual nutrients from experiments in which the other nutrients were available in large excess. Ks values determined from such experiments have been found to depend on species, the form of the limiting nutrient (e.g. nitrate versus ammonia), culture stage and other factors. The same equation is often used to describe the relationship between phytoplankton growth rates and nutrient levels, although when it is used for growth rates it is frequently called the Monod equation. The compilation of Ks values for

diatoms used here (Sarthou *et al.* 2005) included Ks values determined for both nutrient uptake and phytoplankton growth.

As shown in the Results, nutrient conditions in which two or three nutrients are simultaneously at levels comparable to their Ks values occur frequently in the fall in PEI inlets. The oceanographic community has come to recognize in recent years that multiple resources may be limiting in some circumstances, but the details and implications of how this limitation might be manifested in marine phytoplankton have not been explored in depth. However, there are discussions about multiple resource limitation in the microbiology literature (e.g. McGee 1972; Bader 1978, 1982; Mankad and Bungay 1988). Bader (1978) discussed interactive and non-interactive models for multiple nutrient limitation. A fully interactive model for limitation by two nutrients (e.g. nitrogen and phosphorus) could be written:

$$V = V_{max} * \frac{[N]}{[N] + K_N} * \frac{[P]}{[P] + K_P} = V_{max} * TA \qquad (2)$$

where TA = the Total Attenuation of the growth rate by nutrient limitation due to nitrogen (N) and phosphorus (P), and K_N and K_P are the Ks values for N and P, respectively. A fully non-interactive model for the same example would be one in which the uptake/growth rate is the minimum value determined by applying Eq. (1) separately to N and P. Bader (1978) considered the conditions under which interactive and non-interactive models would apply. To state his conclusion in very general terms, interactive models are appropriate when two or more resources are involved in the same enzymatic pathways. Pragmatically, some interaction probably occurs even in cases where the metabolic pathways are not obviously linked, due to the stresses caused by sub-optimum conditions.

However, to our knowledge, such extensions of the Michaelis-Menten / Monod equation to multiple nutrient limitation has never been experimentally tested for marine phytoplankton. Such experiments present challenges, but would be very informative. An alternative approach for testing hypotheses about resource limitation would be to apply the "Resource-ratio Theory", originally developed by Tilman for phytoplankton (Tilman 1977) and then extended to many other organisms (reviewed by Miller *et al.* 2005). Our treatment here will be limited to the Michaelis-Menten / Monod models.

For the purposes of examining nutrient limitation in PEI inlets, we will assume that N and P interact in limiting growth, on no firmer grounds that they are both essential to the production of macromolecules, but that Si limitation is independent of N and P. For dinoflagellates, TA will be the value from Eq. (2) for N and P; for diatoms, TA will be either the value of TA from Eq. (2) for N and P or the attenuation factor, [Si] / ([Si] + K_{Si}), from Eq. (1) for Si, whichever is less.

We will evaluate nutrient limitation in PEI inlets based on the two concepts just described: we will use elemental ratios (N:P, based on TIN, and Si:N) and the ratios described in the Introduction (N:P < 16 implies N is more limiting than P; Si:N < 1 or Si:P < 16 implies that Si is more limiting than N or P) to determine which of the nutrients limits carrying capacity. We will determine the limiting nutrient for carrying capacity for diatoms based on N, P and Si

requirements, and for non-siliceous phytoplankton (mostly dinoflagellates) based on just N and P. We will also use TA, based on mean values of K_N = 1.6, K_P = 0.24 and K_{Si} = 3.9 μM from Sarthou *et al.* (2005), as an approximate indicator of how severely diatom growth rates may be limited by low values of either N+P, or Si. A similar index could be constructed for non-siliceous phytoplankton in which TA depended only on N and P levels, but in the absence of a compilation for Ks values comparable to that of the diatom compilation by Sarthou *et al.* (2005), we have not attempted to use such an index. Nutrient concentrations during the spring would be expected to be higher than those described here. The conclusions of this analysis should therefore not be extrapolated beyond the late summer and fall periods during which we have collected nutrient data.

Figure 20 shows the nutrient-limiting conditions in Cardigan River. In this and similar figures (Figs. 21-24), the limiting nutrient for carrying capacity, for both diatoms and dinoflagellates, is shown by the coloured bars at the top of each graph. The attenuation factor for diatom growth for each nutrient, based on Eq. (1) and the Ks values from Sarthou *et al.* (2005), are plotted with the lines and symbols. The total attenuation of diatom growth rates, whether due to N+P or Si based on our scenario for multiple nutrient limitation, is indicated by the top of the shaded polygon. When the top of the polygon coincides with the Si attenuation factor, diatom growth rate is limited by Si; when it does not, diatom growth rate is limited by the combined effects of N and P

According to our analysis, carrying capacity for dinoflagellates in Cardigan River was limited by either N or P for significant times in 2001 and 2002, but mostly by N in 2003. Carrying capacity for diatoms was usually limited by Si or N, with Si limitation slightly more frequent, and one brief period of P limitation in 2003. Such shifts in patterns are found in many other inlets as well. Diatom growth rates in Cardigan River were limited by N+P for periods of about one month (approximately October) in 2001 and 2003. In 2002, attenuation factors due to N+P and Si were similar, with the limiting factor changing back and forth between N+P and Si until November, when Si limitation became dominant. It is also clear from Figure 20 that the nutrient which limits diatom carrying capacity is not necessarily the same as the one which limits diatom growth. This is true because the ratios of Ks values for the different nutrients are not the same as the Redfield ratios, and because of the assumed enzymatic interactions between N and P. The TA values were low, with mean values of 0.23, 0.31 and 0.29 in 2001, 2002 and 2003. In other words, diatom growth was reduced to 23 to 31% of maximal values by the occurrence of low concentrations for the three nutrients. While this conclusion is based on both the average Ks values used, and on the assumptions inherent in the Michaelis-Menten equations extended to multiple nutrients, these low values of TA underscore the importance of testing multiple nutrient limitation, and the suitability of Eq. (2), when more than one nutrient is at low levels.

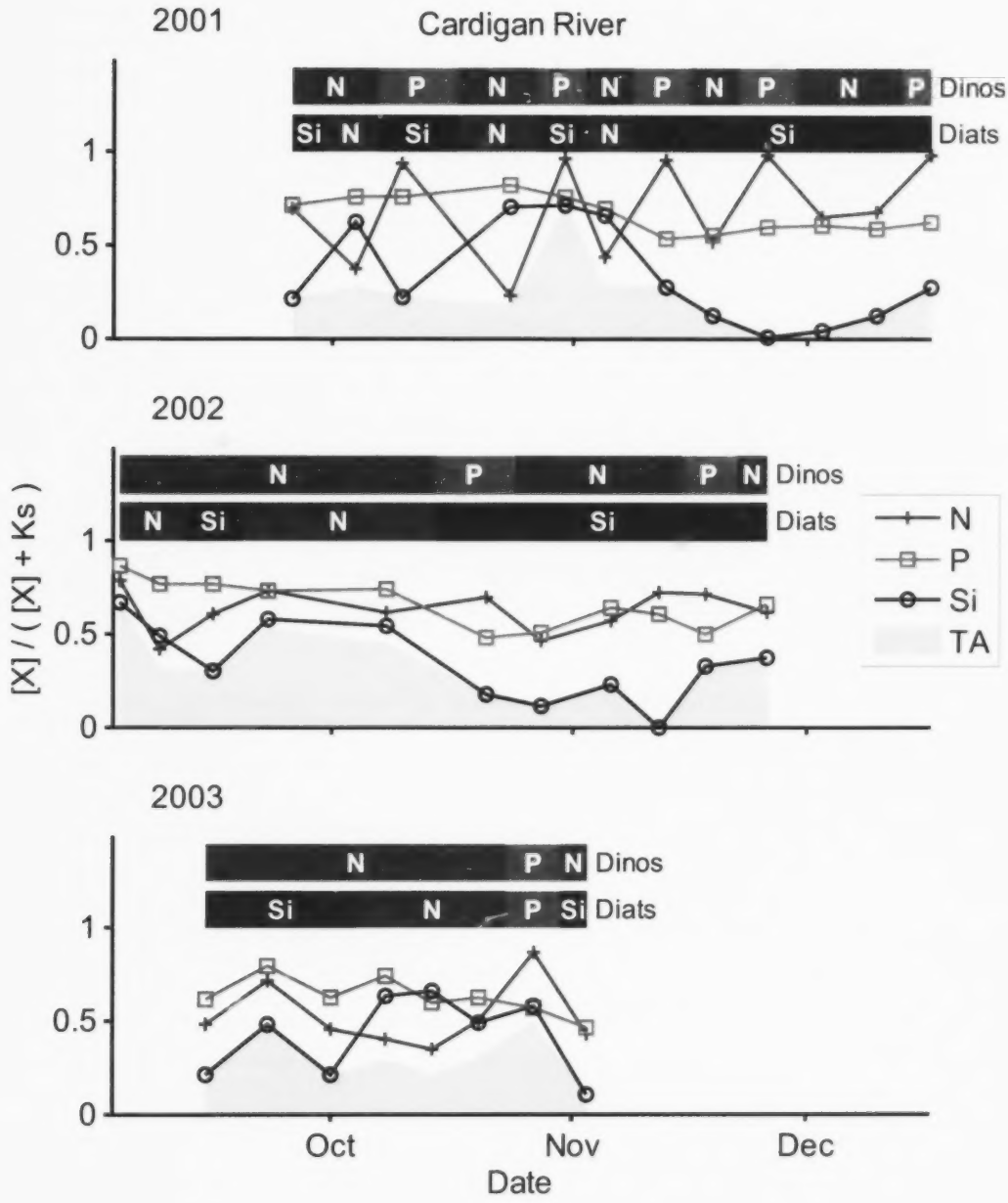

Fig. 20. Nutrient limitation in Cardigan River, PEI. The three lines indicate the attenuation of the diatom growth rate by each nutrient, and the top of the shaded area shows the total attenuation (TA) of the diatom growth rate by either (N+P) or Si (see text). The two bars indicate which nutrient limits the carrying capacity for dinoflagellates (Dinos) or diatoms (Diats). The colours in the bars are the same as those in the legend for the lines.

Figure 21 shows nutrient-limiting conditions in Lennox Channel. Conditions here are somewhat different from those in Cardigan River. Dinoflagellate carrying capacity in Lennox Channel was always limited by N, except for one brief period of P limitation late in 2001. Diatom carrying capacity was limited by Si throughout 2001, with a mix of Si and N limitation in 2002 and 2003. The relative importance of Si and N limitation in 2002 and 2003 were similar to that seen in Cardigan River, but the periods during which each were limiting to diatom carrying capacity in the two inlets were different. Also unlike Cardigan River, diatom growth rates in Lennox Channel were almost always limited by Si. Mean TA values were also lower in Lennox Channel, with means of 0.047, 0.11 and 0.22 in 2001, 2002 and 2003, respectively.

Figure 22 shows nutrient-limiting conditions in New London Bay. Dinoflagellate carrying capacity showed a mix of N and P limitation, more like that of Cardigan River than Lennox Channel. Diatom carry capacity in New London Bay was more similar to that in Lennox Channel, with Si dominating in 2001 and 2002. In all three years, Si was almost always more limiting to diatom growth rate than N+P. TA values were intermediate between those seen in Cardigan River and those in Lennox Channel, with means of 0.09, 0.25 and 0.26, for 2001, 2002 and 2003, respectively.

Figure 23 shows nutrient-limiting conditions in Tracadie Bay. Overall patterns are similar to those in New London Bay, except that some P limitation occurs for both dinoflagellate and diatom carrying capacity in 2003. Mean TA values were 0.25, 0.29 and 0.33 in 2001, 2002, and 2003, respectively.

Figure 24 shows nutrient-limiting conditions in Rustico Bay, in which P limitation of both dinoflagellate and diatom carrying capacity was more dominant than in any other inlet. Other inlets that also showed significant periods of P limitation include Brudenell River, St. Marys Bay, and St. Peters Bay. Despite the low P values necessary to produce P limitation in Rustico Bay, diatom growth rate was still usually limited by Si, except for a period of about one month in September-October, 2002.

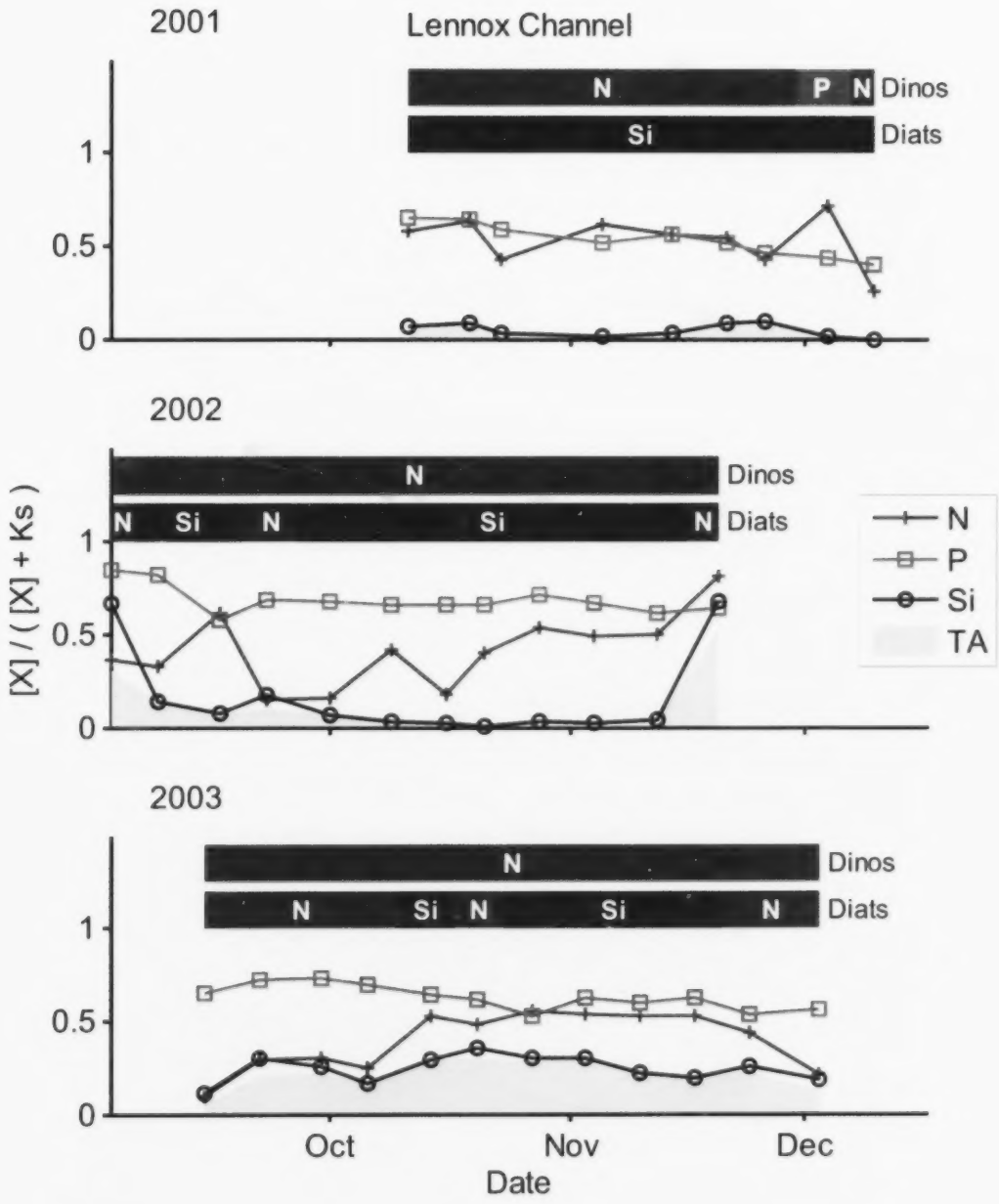

Fig. 21. Nutrient limitation in Lennox Channel, PEI. The three lines indicate the attenuation of the diatom growth rate by each nutrient, and the top of the shaded area shows the total attenuation (TA) of the diatom growth rate by either (N+P) or Si (see text). The two bars indicate which nutrient limits the carrying capacity for dinoflagellates (Dinos) or diatoms (Diats). The colours in the bars are the same as those in the legend for the lines.

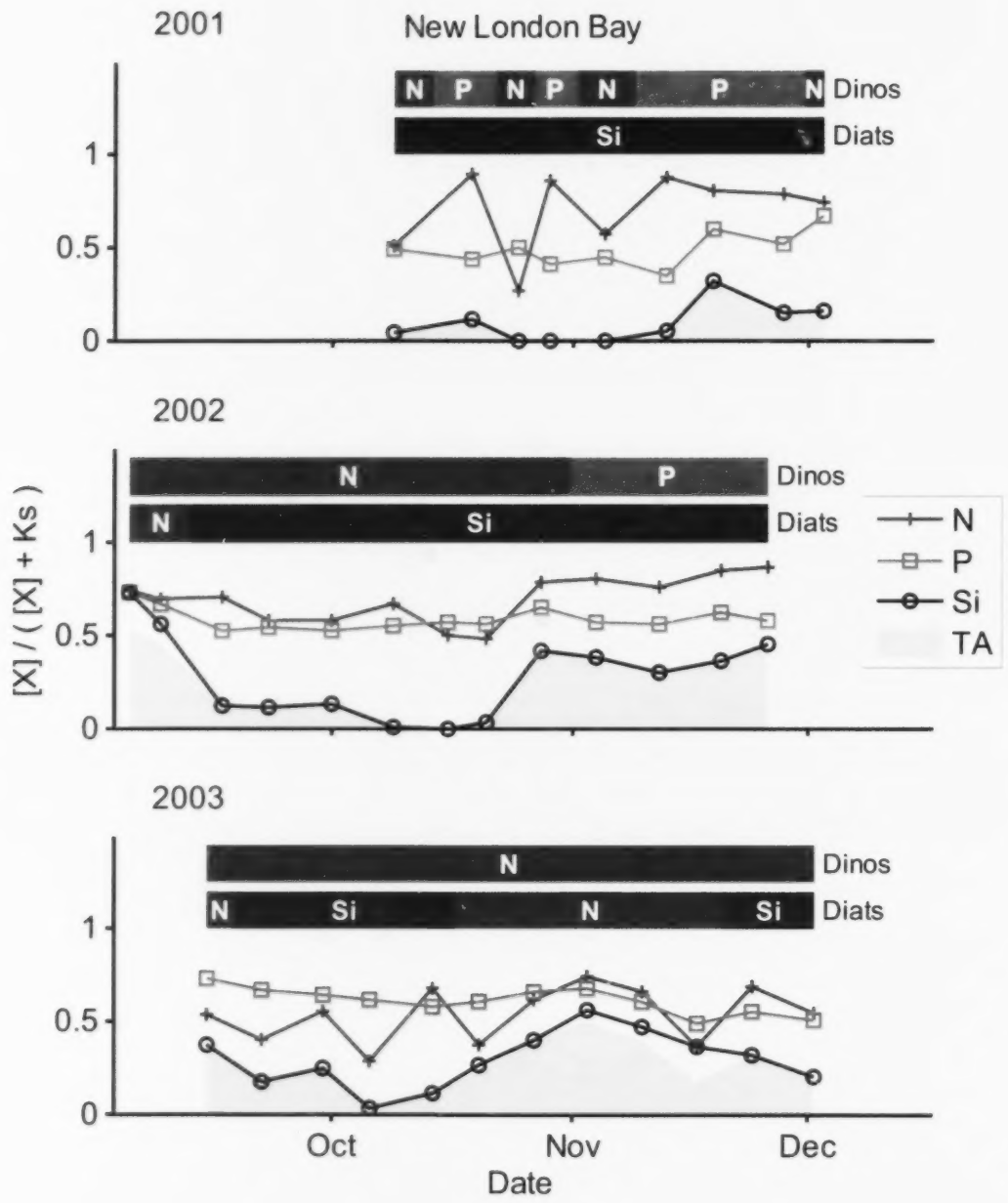

Fig. 22. Nutrient limitation in New London Bay, PEI. The three lines indicate the attenuation of the diatom growth rate by each nutrient, and the top of the shaded area shows the total attenuation (TA) of the diatom growth rate by either (N+P) or Si (see text). The two bars indicate which nutrient limits the carrying capacity for dinoflagellates (Dinos) or diatoms (Diats). The colours in the bars are the same as those in the legend for the lines.

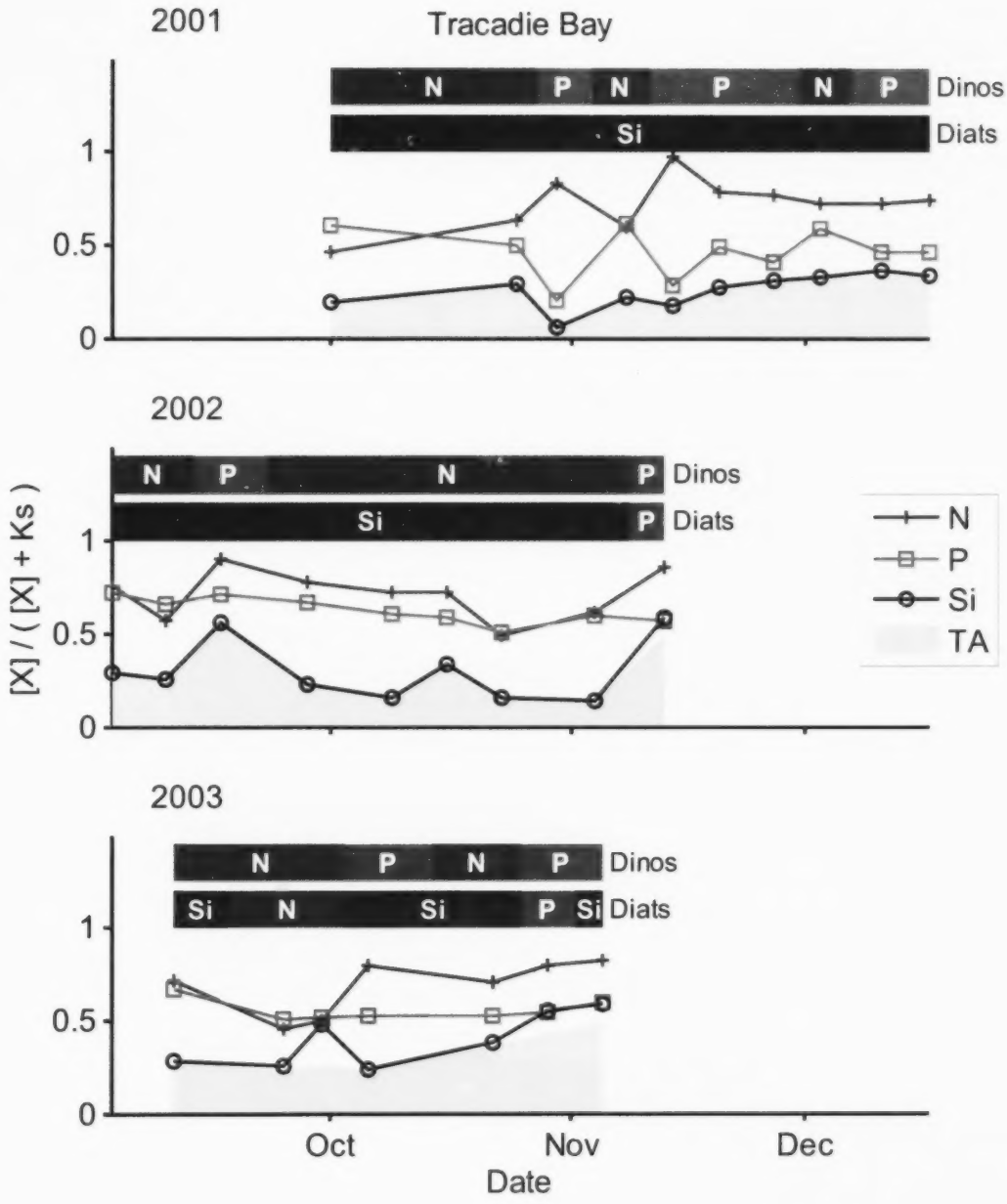

Fig. 23. Nutrient limitation in Tracadie Bay, PEI. The three lines indicate the attenuation of the diatom growth rate by each nutrient, and the top of the shaded area shows the total attenuation (TA) of the diatom growth rate by either (N+P) or Si (see text). The two bars indicate which nutrient limits the carrying capacity for dinoflagellates (Dinos) or diatoms (Diats). The colours in the bars are the same as those in the legend for the lines.

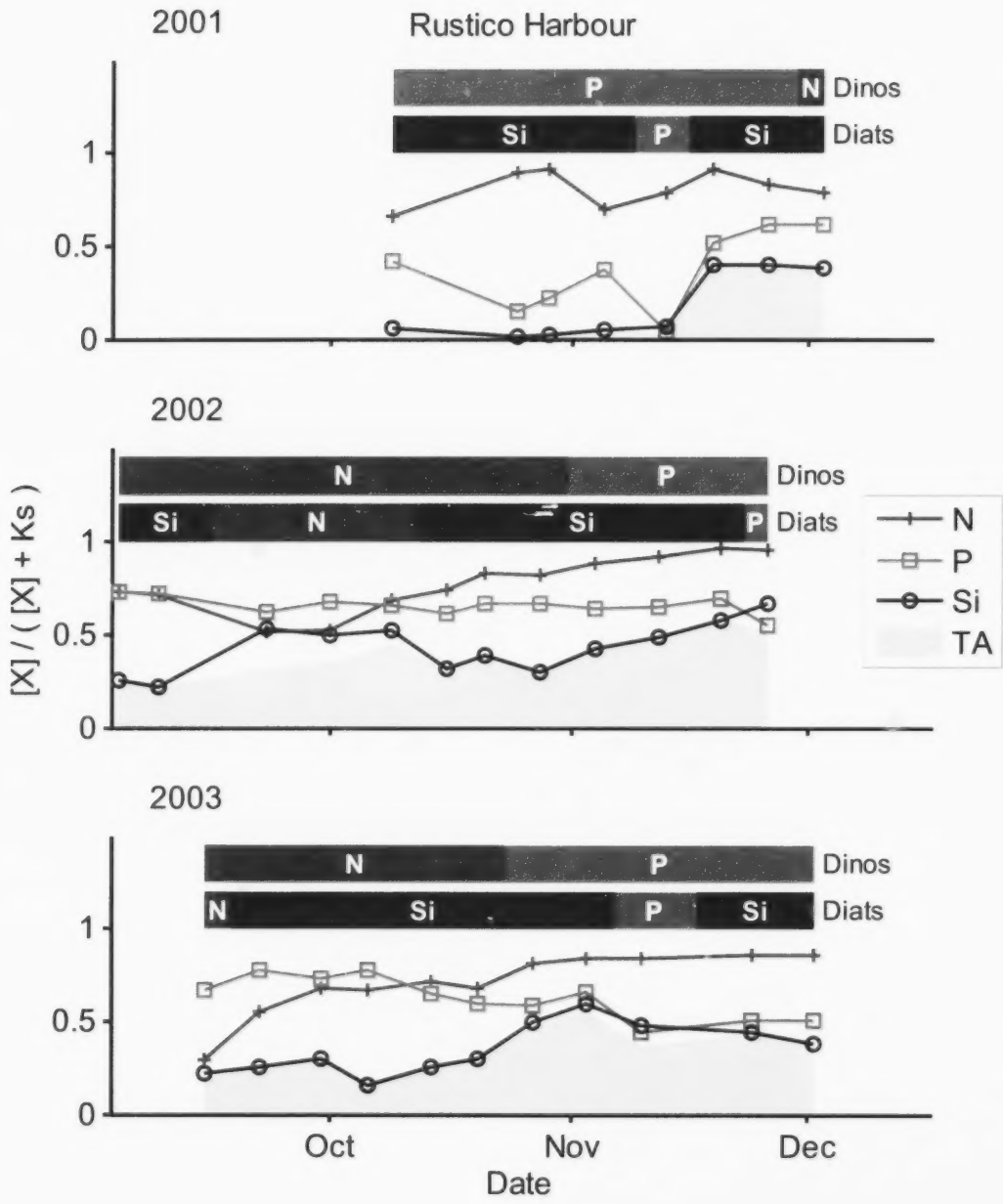

Fig. 24. Nutrient limitation in Rustico Bay, PEI. The three lines indicate the attenuation of the diatom growth rate by each nutrient, and the top of the shaded area shows the total attenuation (TA) of the diatom growth rate by either (N+P) or Si (see text). The two bars indicate which nutrient limits the carrying capacity for dinoflagellates (Dinos) or diatoms (Diats). The colours in the bars are the same as those in the legend for the lines.

On the basis of the entire nutrient dataset, dinoflagellate carrying capacity was limited by N in 74% of the samples and by P in 26%. Diatom carrying capacity was limited by Si in 75% of samples, by N in 21% and by P in 4%. Figure 25 shows the distribution of the growth attenuation factors for diatoms for the different elements and the resulting TA. The strong similarities between the distributions for the Si attenuation factor and TA clearly show that Si has the most impact on diatom growth rates: the median attenuation due to Si is 0.27. The attenuation factors for N can also be low, but many also occur in the range between 0.5 and 0.8, similar to the values found for P. Diatom growth was limited by Si in 72% of the samples; by N and P in 28%. To the extent that Eq. (2) overemphasizes the importance of interactions between N and P in limiting growth, this estimate for the proportion of the time that Si limits diatom growth is a lower limit.

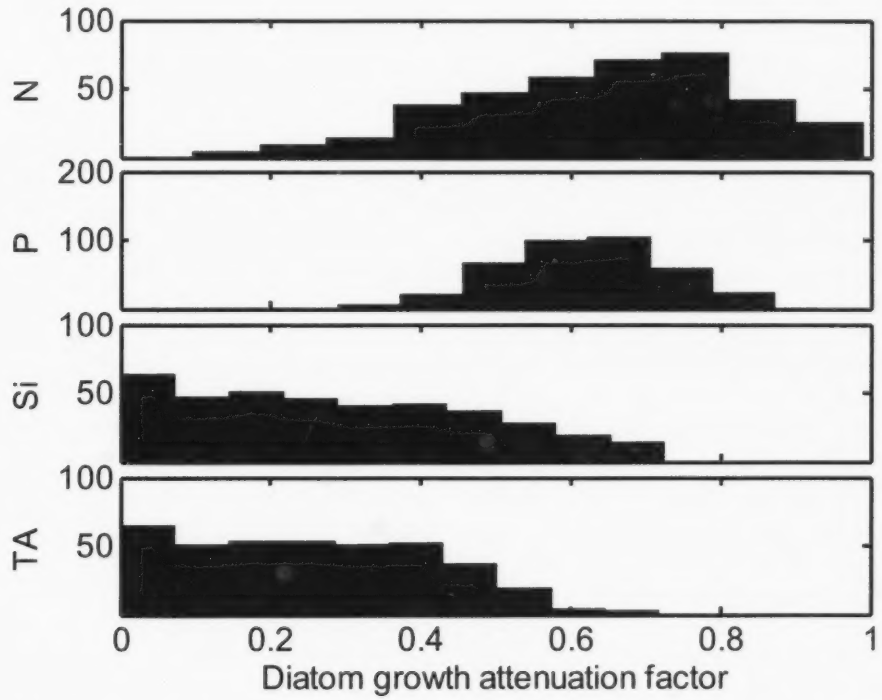

Fig. 25. Distribution of diatom growth attenuation factors ([X] / ([X] + K_X)) for each nutrient and the total attenuation factor (TA, see text).

The net effect of these attenuation factors is to reduce growth rates to a small fraction of the potential growth: 75% of the TA values were < 0.38; 50% were < 0.24. Despite the assumptions and simplifications in these calculations, these TA values emphasize the need to assess growth rates under realistic conditions, i.e. having low concentrations of more than one nutrient.

A number of general conclusions can be drawn from this discussion of nutrient limitation of carrying capacity and growth rates. Both N and P can limit the carry capacity for dinoflagellates. Si limits diatom carrying capacity about 75% of the time, with N responsible most of the rest of the time; P limitation is less common. The prevalence of Si limitation of diatom growth rates (78% of the time) suggests that a diatom species with an unusually low Ks value for Si would have a competitive advantage in these waters. Comparisons among the different inlets show that patterns of limitation are variable, both between inlets in the same year and between years in the same inlet. It is also clear that the nutrient that apparently limits diatom carrying capacity can be different from the one(s) limiting diatom growth. Although the details of all these conclusions are subject to the Redfield ratios and Ks values we used, and our speculative formulation of a multiple limitation model, it is clear that N, P and Si in these PEI inlets are all at sufficiently low levels that they may have a role in limiting carrying capacity and growth rates. Laboratory experiments to test the responses of phytoplankton to such low levels of multiple nutrients could be very useful in understanding phytoplankton dynamics in such environments.

Nutrient-Phytoplankton Relationships

The form, concentrations, and relative amounts of nutrients in seawater have long been recognized as some of the important factors that determine the abundance, species composition and species succession of marine phytoplankton. More recently, as noted in the Introduction, laboratory studies have shown that nutrient levels may also control important physiological processes of phytoplankton, such as the production of domoic acid by *Pseudo-nitzschia* species. Some general truisms of these relationships between nutrients and phytoplankton are widely supported by field research, such as the replacement of diatoms by dinoflagellates when silicate levels decrease on seasonal scales through the course of a spring bloom, or on longer scales through changes in the relative amounts of nutrients present in freshwater discharges. But verifying more subtle details of these relationships between nutrients and phytoplankton in field studies has always been challenging. Complicating factors include: the variability of both nutrients and phytoplankton on many different spatial and temporal scales; time lags between changes in nutrients and phytoplankton response; the possibility that the current status of phytoplankton reflects the nutrient history integrated over many months; factors other than nutrients that may more strongly affect phytoplankton population dynamics, etc.

We have examined our extensive nutrient and phytoplankton datasets, collected in PEI inlets, for evidence of and insights into relationships between phytoplankton numbers, species composition and nutrient levels. Since no instances of domoic acid toxicity occurred during 2001 to 2003, we could not include the influence of nutrients on toxin production. The basic premise underlying the identification of such relationships is that there is sufficient variability in nutrient conditions, among the 14 inlets or the three years of sampling, to trigger observable differences in the phytoplankton community. Practical difficulties include both natural variability and the potential for different kinds of aliasing in our dataset, as described in the Materials and Methods section.

We used a cluster analysis on the nutrient data to compare nutrient levels in different inlets and different years. This analysis breaks down the data into 41 different objects: 14 inlets x 3

years, minus 1 missing inlet (March Water was not sampled for phytoplankton in 2002, so the corresponding nutrient data will not be used either). The NO_3, NH_3, TIN, Si, and PO_4 data used to characterize each inlet are from the samples collected closest in time to the average dates of phytoplankton for those inlets sampled once per year (these dates are shown by the vertical lines in Fig. 2), transformed as described in the Results section. Figure 26 shows a dendrogram based on a hierarchical cluster analysis of these data, using the Pearson correlation coefficient as a distance measure (actually 1-R) and average linking. The dendrogram shows that different inlet / year combinations separate cleanly into five clusters (as shown by the five colours), at a distance measure of 0.45.

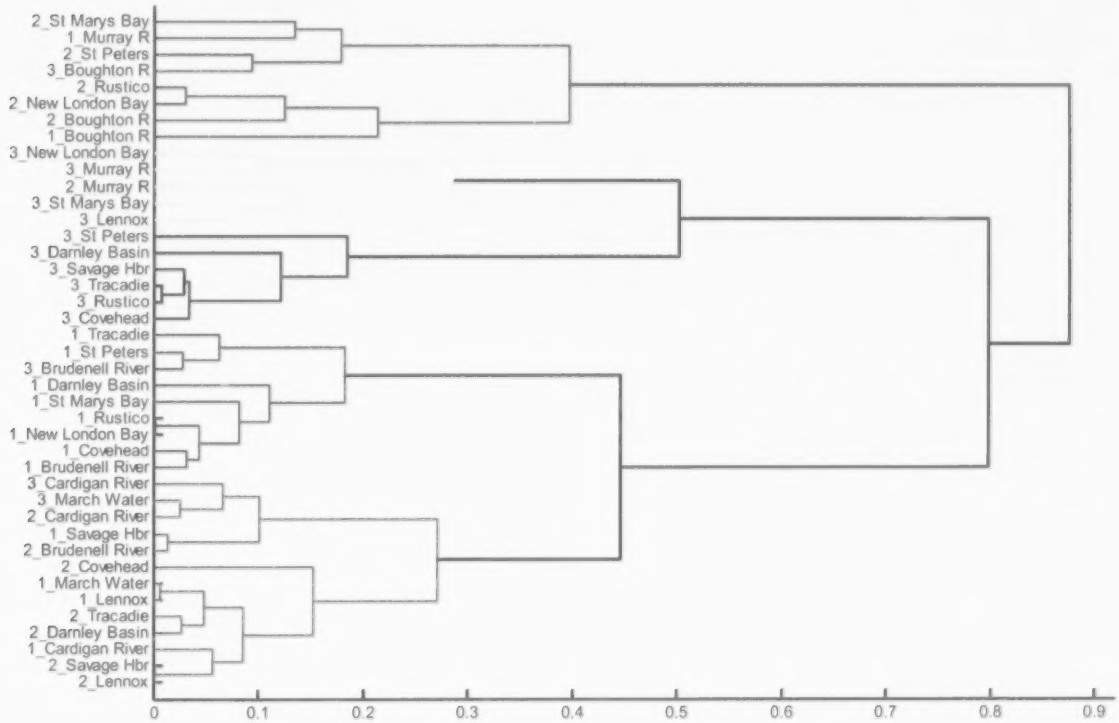

Fig. 26. Hierarchical cluster analysis of nutrient data. The prefixes to inlet names indicate whether nutrient measurements were for 2001, 2002, or 2003.

Both this cluster analysis and the identification of differences between the inlets by the analysis of variance (see Results) show that there are variations in nutrient conditions in the study area which might be responsible for changes in the phytoplankton community. A working hypothesis for testing whether there are differences in the phytoplankton community that correspond to the differences between nutrient clusters can be formulated as follows. If there are such differences in the phytoplankton community, then phytoplankton from inlets / years in the same cluster (e.g. Boughton River 2001 and Boughton River 2002) should be more similar to each other than phytoplankton from inlets / years in different clusters (e.g. Boughton River 2001

and New London Bay 2003). We tested this hypothesis by randomly selecting 1000 pairs of inlets / years from the same cluster and 1000 pairs from different clusters and calculating the Bray-Curtis similarities for each of those pairs, based on i) the actual counts for all phytoplankton species, and ii) presence / absence for all species. Table 11 shows the results of the analysis on one such set of randomly drawn pairs.

Table 11. Similarities of phytoplankton communities within the same nutrient cluster and between different nutrient clusters.

	Actual Counts	**Presence / Absence**
Median Values		
Within clusters	0.253	0.482
Between clusters	0.045	0.466
p values		
Mann-Whitney U-test	$\sim 10^{-44}$ *	0.009 *
Sign test	$\sim 10^{-35}$ *	0.700

* Similarity within the same cluster significantly greater than between different clusters at $p = 0.05$

The above table shows that the similarities within the same cluster are greater than those between different clusters, but are these differences significant? Since these Bray-Curtis similarities are not normally distributed, non-parametric tests are appropriate for comparing their values. Both the Mann-Whitney U-test and the sign test show that the similarities based on actual counts are significantly greater within clusters at a very high probability, a conclusion that does not depend on the set of random samples. However, the two tests disagree about the significance of the difference based on presence / absence data. In fact, the conclusions of both tests for presence / absence data depend on the random set of pairs selected. In other words, dividing different inlets / years into clusters based on nutrients also groups phytoplankton communities that are clearly similar in species abundance, but does not clearly group communities according to species assemblages. Nevertheless, this analysis has identified an unequivocal link between nutrients and phytoplankton in these field data.

This attempt to find differences in the phytoplankton that correspond to the clustering of inlets based on nutrients is typical of many of our attempts to find relationships between the nutrient and phytoplankton information in our dataset: many tests have shown statistically significant relationships between nutrients and phytoplankton, but insights into possible causal links between nutrients and phytoplankton (e.g. species X prefers low levels of nutrient 1 and high levels of nutrient 2) have been elusive. Examining many times series plots of nutrient and phytoplankton data, grouped in many different ways, has not revealed any general trends. In an attempt to identify more specific relationships between nutrient conditions and phytoplankton communities, we have applied a number of different bivariate and multivariate techniques to the PEI nutrient and phytoplankton data.

Spearman correlation analysis is a technique that has been used to relate environmental conditions to phytoplankton parameters (e.g. Caroppo *et al.* 2005). Spearman correlations have distinct advantages for the analysis of this type of dataset: since they are non-parametric, conclusions are independent of transformation of the nutrient or the phytoplankton data. We calculated Spearman correlations between five nutrients (NO_3, NH_3, TIN, Si, PO_4) and 85 different measures of the phytoplankton community for all cases with simultaneous measurements of nutrients and phytoplankton (n = 146). These measures include counts for all individual species with at least five non-zero counts (a total of 78 species), and total counts for the following seven groups: phytoplankton (i.e. all species); dominant species (those species with at least one count > 100,000 cells L^{-1}); all diatoms; centric diatoms; pennate diatoms; *Pseudo-nitzschia*; dinoflagellates. Zero counts were excluded, because large numbers of zero values bias the Spearman correlations. The semi-quantitative data collected for some inlets in 2001 were also excluded, since meaningful rank orders cannot be determined from those data. Pairwise deletion was used to remove missing data.

Table 12 shows the results of this correlation analysis. Of the 425 possible correlations between nutrient levels and measures of phytoplankton, 86 were significant at $p < 0.05$. At this level of significance, 21 correlations would be expected by chance alone, suggesting that most of these 86 correlations are real. Forty of the 78 species tested and all seven "total" measures correlated with at least one nutrient. Generally speaking, the fractions of the variance in the rank order data explained by these correlations, as indicated by the rho^2 values, were small: in 75% of the cases, the correlations explained less than 26% of the variance. This observation is not surprising, given the complexity of nutrient-phytoplankton interactions. Most of the cases in which a high fraction of the variance was explained were those with a small n; this is an artefact of the Spearman analysis.

Twenty-one of the 22 significant correlations between NO_3 and the phytoplankton are negative (the sole exception is a correlation with only five points). The same is true for all of the significant correlations between NH_3 or TIN and phytoplankton (there are 21 significant correlations in each case). These negative correlations are indications that inorganic nitrogen is being taken up by phytoplankton, and released by the recycling of phytoplankton through grazing and other processes, sufficiently quickly that these transformations exert significant control on nitrogen levels despite the relative short flushing times in these inlets (a few days).

Table 12. Significant Spearman correlations ($p < 0.05$) between nutrients and measures of phytoplankton abundance.

Phytoplankton	Nutrient	rho	rho^2	p	n
Armoured dinoflagellate	NO_3	-0.439	0.193	0.000	92
	NH_3	-0.305	0.093	0.003	92
	TIN	-0.394	0.155	0.000	92
Asterionellopsis glacialis	Si	-0.443	0.197	0.044	21
Cerataulina pelagica	NH_3	-0.254	0.065	0.039	66
Ceratium fusus	Si	0.818	0.669	0.010	9
	PO_4	0.783	0.614	0.016	9
Chaetoceros contortus	Si	0.245	0.060	0.038	72
Chaetoceros danicus	NO_3	-0.649	0.421	0.002	20
	TIN	-0.566	0.321	0.009	20
Chaetoceros debilis	PO_4	-0.397	0.158	0.040	27
Chaetoceros spp.	NH_3	-0.262	0.069	0.003	129
	TIN	-0.243	0.059	0.005	129
Chrysochromulina parkeae	TIN	-0.855	0.730	0.021	7
Cylindrotheca closterium	NO_3	-0.278	0.077	0.003	115
	NH_3	-0.259	0.067	0.005	115
	TIN	-0.299	0.090	0.001	115
	Si	0.239	0.057	0.010	115
Dactyliosolen fragilissimus	NO_3	-0.202	0.041	0.044	100
Detonula confervacea	NO_3	0.975	0.950	0.033	5
Dinobryon spp.	TIN	-0.377	0.142	0.044	29
Eutreptia / Eutreptiella	NO_3	-0.242	0.059	0.036	75
	TIN	-0.292	0.085	0.011	75
Guinardia delicatula	NH_3	-0.205	0.042	0.026	118
	TIN	-0.197	0.039	0.033	118
Gyrodinium spp.	NH_3	-0.448	0.201	0.005	37
	TIN	-0.401	0.161	0.014	37
Gyrosigma littorale	NO_3	-0.544	0.296	0.029	16
	PO_4	0.654	0.428	0.006	16
Karenia mikimotoi	Si	0.441	0.195	0.001	51
Lennoxia sp.	PO_4	0.480	0.231	0.032	20
Leptocylindrus danicus	NH_3	-0.411	0.169	0.009	39
	TIN	-0.335	0.112	0.037	39
Merismopedia sp.	NO_3	-0.943	0.889	0.017	6
Mesodinium rubrum	NO_3	-0.262	0.069	0.015	85
	NH_3	-0.219	0.048	0.044	85
	TIN	-0.228	0.052	0.036	85
Microcystis sp.	NO_3	-0.688	0.473	0.019	11
Navicula sp.	NH_3	-0.698	0.487	0.042	9
	TIN	-0.775	0.600	0.019	9
Phalacroma sp.	Si	0.478	0.229	0.045	18
Pleurosigma angulatum	NO_3	-0.549	0.301	0.001	36
	NH_3	-0.357	0.128	0.032	36
	TIN	-0.470	0.221	0.004	36
Preperidinium meunieri	Si	0.986	0.971	0.006	6

Phytoplankton	Nutrient	rho	rho^2	p	n
Prorocentrum micans	Si	0.378	0.143	0.033	32
	PO_4	0.433	0.187	0.013	32
Pseudo-nitzschia americana	NO_3	-0.672	0.452	0.008	14
	NH_3	-0.627	0.393	0.016	14
	TIN	-0.659	0.434	0.010	14
Pseudo-nitzschia delicatissima	NO_3	-0.294	0.087	0.038	50
	Si	-0.592	0.351	0.000	50
Pseudo-nitzschia calliantha	Si	-0.424	0.180	0.000	132
Pseudo-nitzschia multiseries / pungens	Si	0.232	0.054	0.014	112
Rhizosolenia hebetata var. *hebetata*	Si	0.506	0.256	0.016	22
Rhizosolenia hebetata var. *semispina*	NO_3	-0.327	0.107	0.001	101
Rhizosolenia imbricata	NO_3	-0.257	0.066	0.016	88
Rhizosolenia pungens	NO_3	-0.360	0.130	0.036	34
	Si	0.355	0.126	0.039	34
Striatella unipunctata	NH_3	-0.719	0.518	0.002	16
	TIN	-0.577	0.333	0.019	16
Thalassionema nitzschioides	NH_3	-0.513	0.263	0.001	40
	TIN	-0.339	0.115	0.032	40
Thalassiosira spp.	NO_3	-0.256	0.065	0.035	68
Unarmoured dinoflagellate	NH_3	-0.320	0.102	0.041	41
Totals					
All species	NO_3	-0.289	0.084	0.000	146
	NH_3	-0.329	0.108	0.000	146
	TIN	-0.292	0.085	0.000	146
Dominant species	NO_3	-0.286	0.082	0.000	146
	NH_3	-0.328	0.107	0.000	146
	TIN	-0.288	0.083	0.000	146
	Si	-0.171	0.029	0.039	146
All diatoms	NO_3	-0.267	0.071	0.001	146
	NH_3	-0.344	0.119	0.000	146
	TIN	-0.304	0.092	0.000	146
	Si	-0.218	0.047	0.008	146
Centric diatoms	NO_3	-0.227	0.052	0.007	138
	NH_3	-0.252	0.064	0.003	138
	TIN	-0.263	0.069	0.002	138
Pennate diatoms	Si	-0.428	0.183	0.000	146
Pseudo-nitzschia	Si	-0.419	0.176	0.000	143
Dinoflagellates	NO_3	-0.300	0.090	0.001	125
	NH_3	-0.204	0.041	0.023	125
	TIN	-0.238	0.056	0.008	125
	Si	0.180	0.032	0.045	125
	PO_4	0.275	0.076	0.002	125

The correlations between Si and PO_4 and the phytoplankton are more often positive than negative (11 of 18 cases for Si; five of six cases for PO_4). All five of the correlations between individual dinoflagellate species and Si were positive, as was the correlation between total dinoflagellates and Si. On the surface, a positive relationship between silicate and dinoflagellates seems to contradict conventional thinking, and may call into question simple interpretations of this correlation analysis. Correlations between Si and diatom species were mixed for both centric diatoms (two positive, one negative) and pennate diatoms (two positive, three negative). In fact, the sign of the correlation with Si was not even consistent for the three different *Pseudo-nitzschia* species. The significance, if any, of the correlations between phytoplankton and Si or PO_4 is unclear.

This Spearman correlation analysis was also applied to phytoplankton data lagged approximately one week behind nutrient data on the supposition that phytoplankton would take some time to respond to changes in nutrient levels. This dataset was formed by finding nutrient samples taken between four and 10 days prior to phytoplankton samples in the same inlet, with the sample collected closest to seven days before selected if more than one nutrient sample occurred in this time window. The results for NO_3, NH_3, and Si were similar to the analysis of the simultaneous data, although there were fewer significant correlations in the lagged dataset than in the simultaneous one, due perhaps to the fewer number of samples in the lagged data ($n = 131$ versus $n = 146$). However, there was a distinct difference for PO_4. In the lagged data, there were 12 significant correlations, compared to six in the simultaneous data. Once again, all but one of these correlations was positive. Apparently, high PO_4 levels one week predict high numbers of some phytoplankton the next week.

Multivariate techniques might also reveal relationships between nutrient and phytoplankton levels. The common parametric techniques assume that the variables have normal distributions. Of the 67 phytoplankton species with more than 10 non-zero counts (quantitative data), only eight are normally distributed, but logarithmic transformation leads to normal distributions for 62 species (Jarque-Bera test, $p = 0.05$). We used the transformed phytoplankton data (for quantitative counts > 0), together with the simultaneous nutrient data described in the Results section (i.e. logarithmic transformation for NO_3, NH_3 and Si; no transformation for PO_4), in a principle component analysis (PCA) of nutrients (NO_3, NH_3, Si, PO_4) and the dominant phytoplankton species (the 13 species with at least one count > 100,000 cells L^{-1}). Table 13 shows the loadings determined from a PCA based on the correlation matrix between the variables, pairwise deletion of missing values, and varimax rotation. Six components were extracted, based on a minimum eigenvalue of 1.0. The maximum loadings for each variable are shown in bold and other loadings > 0.4 (an arbitrary cutoff) are underlined to indicate which variables contribute most to each component; in other words, which variables exhibit similar patterns in the dataset. This analysis was restricted to the dominant phytoplankton species so that adequate numbers of samples were available to construct the correlation matrix.

The loadings of variables in each component in a PCA indicate the relative weights of the variables in that component. Loadings with absolute values approaching 1 are heavily weighted; loadings near zero are insignificant. Two variables with the same sign are positively correlated with each other in their influence on that component; two variables with opposite signs are negatively correlated.

Table 13. Principal component analysis of nutrients and 13 dominant species of phytoplankton (those species with at least one count > 100,000 cells L^{-1}). The highest loading for each variable is displayed in bold; other loadings > 0.4 are underlined.

	1	2	3	4	5	6
NO_3	-0.08	0.22	-0.14	0.05	**-0.73**	-0.13
NH_3	0.03	-0.18	0.10	0.05	**-0.72**	-0.07
Si	-0.28	0.39	0.33	**0.54**	-0.37	0.22
PO_4	-0.20	-0.10	**0.76**	0.14	-0.02	0.01
Cerataulina pelagica	**0.74**	-0.03	0.11	0.20	0.36	0.21
Chaetoceros contortus	0.29	**0.82**	0.22	0.06	0.01	0.24
Chaetoceros spp.	0.17	**0.53**	-0.05	0.47	0.45	0.12
Dactyliosolen fragilissimus	**0.65**	-0.14	0.35	-0.02	0.13	0.25
Guinardia delicatula	0.26	0.19	-0.10	-0.12	0.21	**0.84**
Karenia mikimotoi	0.12	-0.07	-0.06	**0.96**	-0.10	0.06
Leptocylindrus minimus	**0.82**	0.03	-0.10	0.13	-0.09	0.10
Prorocentrum minimum	0.33	0.23	**0.79**	-0.17	0.01	0.14
Pseudo-nitzschia delicatissima	0.47	**-0.83**	-0.24	-0.13	0.09	0.23
Pseudo-nitzschia calliantha	0.55	-0.35	-0.33	-0.19	-0.18	-0.22
Pseudo-nitzschia multiseries / pungens	0.11	-0.02	0.33	0.34	0.05	**0.71**
Skeletonema costatum	0.29	0.20	0.40	**0.52**	0.39	-0.33
Thalassiosira nordenskioeldii	-0.29	**0.97**	-0.35	-0.16	0.02	0.06
Variance explained (%)	16.3	18.3	12.4	11.8	10.5	9.9

This PCA does not indicate a strong link between inorganic nitrogen (NO_3, NH_3) and the dominant phytoplankton species. Component 5 is the only one with large loadings for these nutrients, and only one phytoplankton group (*Chaetoceros* spp.) has a loading > 0.4 in this component. Similarly, only component 3 has a large loading for PO_4, and only two species, *Prorocentrum minimum* and *Skeletonema costatum*, have loadings > 0.4 in this component. The maximum loading for Si is in component 4, in which *Chaetoceros* spp., *Karenia mikimotoi*, and *Skeletonema costatum* also have relatively large loadings. The loadings for these three species have the same sign, despite the fact that one is a dinoflagellate (*K. mikimotoi*) and the other two are diatoms, producing the same uncertain relationship between Si and different plankton groups as was seen in the Spearman correlation analysis.

In the PCA, in addition to the high loading of Si in component 4, components 2 and 5 have reasonably high loadings for Si (0.39, -0.37, respectively). Both components also have reasonably high loadings for *Chaetoceros* spp. However in factor 2, the loadings for Si and *Chaetoceros* spp. have the same sign while in factor 5 they have opposite signs, suggesting that some of the variance in the data is explained by a positive relationship between Si and *Chaetoceros* spp., and some by a negative relationship. This sort of contradiction occurred often in our exploration of this dataset with a range of multivariate techniques, which included

multiple linear regression, several different types of cluster analysis, and multi-dimensional scaling. Most of these techniques could identify relationships between the phytoplankton and nutrient levels, and some of these were statistically significant in the results of analyses for which significance can be tested. The fact that we were unable to find clear-cut relationships that might help define the specific nutrient conditions that select for individual phytoplankton species or groups in this dataset for PEI inlets could have several explanations, including: i) nutrient conditions were not variable enough within this dataset to reveal the functional relationships between nutrients and phytoplankton; ii) the data are not detailed enough, or suffer from too many confounding factors to reveal such relationships; or iii) such relationships do not exist in these inlets; or, stated another way, other factors exert much of the control over species selection.

Phytoplankton

Phytoplankton play an integral role in nutrient dynamics within estuaries and coastal inlets (Dame *et al.* 1991; Prins and Smaal 1994; Prins *et al.* 1998; Cranford *et al.* 2003, 2006), and provide the main food source for filter-feeding mussels (Smaal and van Stralen 1990; Dame 1996; Dame and Prins 1998). It is therefore important to know which phytoplankton species are present during the mussels' growing season, and how their abundance changes over time. Given that the mussel aquaculture industry in PEI provides a significant boost to the Island economy (worth $30 million $CAN in 2004; DFO 2005), it is surprising that so little is known about the phytoplankton species composition and bloom dynamics of those waters. Only one study was found that provided some phytoplankton data in relation to aquaculture sites on PEI. Johnson (1988) studied the phytoplankton communities in Murray River and Boughton River, important mussel aquaculture sites in eastern PEI. This was for an undergraduate Honour's Thesis; the timing (11-Aug-87 to 25-Nov-87) fortuitously coincided with the 1987 fall blooms of toxic *Pseudo-nitzschia multiseries* (then referred to as *Nitzschia pungens* forma *pungens*), although during that sampling period the source of the domoic acid had not yet been traced to this diatom species. Nevertheless, the study did provide the first information about the presence and numbers of this diatom and other phytoplankton species during that period. During the 1987 bloom period, Johnson (1988) recorded 29 taxa in Murray River and 21 in Boughton River, considerably lower than the 124 reported in our study, which covered 14 inlets. Our study is therefore the first to provide detailed phytoplankton composition information for inlets of PEI during a multi-year period. Hourly temperature data are available in Smith (2001, 2002, 2003) that cover the same time period and inlets as studied here. However, we did not attempt to interpret our phytoplankton data with respect to temperature.

There was a distinct difference in the total number of phytoplankton cells among the four inlets studied in detail (Table 6). During all three years, Cardigan River exhibited the highest total number of cells and Tracadie Bay the fewest, with Lennox Channel and New London Bay showing similar, intermediate values. A previous study also showed cell abundance differences in Tracadie Bay relative to other water masses. In Tracadie Bay, picoplankton (<2 µm in diameter; counted by flow cytometry using a red fluorescence threshold) were an order of magnitude greater concentration (10^9 cells L^{-1}) than in open oligotrophic oceans and temperate coastal inlets; their small size may enable them to escape grazing by aquacultured mussels,

giving them a competitive advantage over larger phytoplankton species (Li *et al.* 2006b). Consistent with our study, Tracadie Bay large nanophytoplankton (10-20 μm) were less abundant than elsewhere (Bedford Basin, Scotian Shelf, and Labrador Sea) (Bill Li, DFO, Dartmouth, NS, pers. comm.). The unpublished data demonstrating the more abundant picoplankton and fewer large nanoplankton are shown in Figure 27 (courtesy of Bill Li). Because of their small size, we were unable to assess the concentration of picoplankton in our study. However, because it was unusual, we did note the presence of picoplankton in Tracadie Bay in September, 2002, appearing as small dots and/or dashes at the 200 X magnification used.

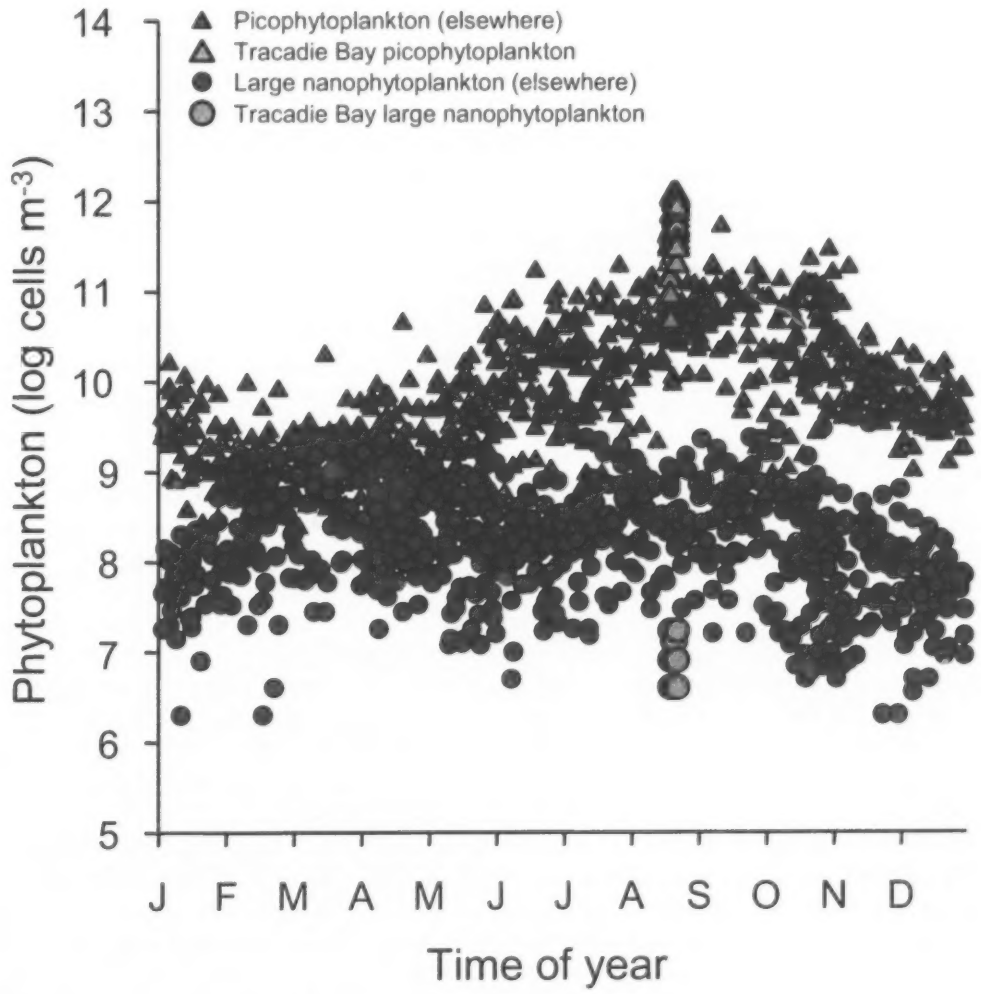

Fig. 27. Abundance of picoplankton and large nanophytoplankton in Tracadie Bay compared to the Bedford Basin, Scotian Shelf, and Labrador Sea. Unpublished graph courtesy of Bill Li (DFO, Dartmouth, NS). The data for the locations other than Tracadie Bay are found in Li *et al.* (2006a).

Reasons for our observed order of magnitude lower total number of phytoplankton cells in Tracadie Bay than in Cardigan River are undoubtedly complex and numerous; we have not collected enough information to explain this difference. Factors that could be considered include: flushing rate, nutrient input rate, competition for nutrients with benthic flora, and differential grazing due to naturally occurring zooplankton and filter feeders (e.g. mussels, clams, oysters, and tunicates). The intensity of mussel aquaculture could also be an important factor. Aquaculture lease area coverage of the inlets is presently the only proxy available for mussel sock stocking density. Cardigan River has a surface area of 616 hectares (Gregory *et al.* 1993), of which 162 hectares are taken up by leases (L. Comeau, DFO, Moncton, NB, pers. comm.) (Appendix A3); this represents a 19.9% coverage of the inlet. In contrast, Tracadie Bay has almost a four-fold greater lease area (607 hectares), giving a 37.0% lease coverage, out of a total 1,440 hectare bay area (Appendix A14). However, lease area alone does not provide information about mussel stocking density; indeed, some lease sites are not used and others are not fully stocked. To better evaluate if the intensity of mussel aquaculture has an impact on the magnitude of phytoplankton populations, it will be necessary to collect accurate data for mussel sock stocking density and harvesting tonnage, for each lease and inlet. These data are not currently available, but efforts are underway to collect and track them, thus enabeling calculation of stocking density. This type of information could also be used to develop indices that would assess possible impacts of mussel aquaculture on phytoplankton.

The most abundant species found during our study was the centric diatom that we identified as *Skeletonema costatum* (Table 8). This species had previously been considered to be cosmopolitan, and one of the most abundant diatoms in the coastal marine phytoplankton community (Zingone *et al.* 2005). However, recent morphological and molecular studies (Sarno *et al.* 2005; Zingone *et al.* 2005) have now shown that what had been published as *S. costatum* in over 548 papers since 1990, could actually have been any of eight other similarly looking species, four of which were known and four of which constitute new species recently named by Sarno *et al.* (2005). This re-evaluation of the *Skeletonema costatum* nomenclature was published after our samples were collected and species identified. We therefore cannot be certain of the exact identity of what we have called "*Skeletonema costatum*" in this report. Scanning electron microscopy, and/or rDNA sequence data would be required to identify definitively which species of *Skeletonema* were actually present during our study. A later attempt to re-examine FAA-preserved material unfortunately showed that most of the diatom frustules had become dissolved in this preservative (except for some robust *P. pungens*), even in the 2003 samples, making it impossible to find any remaining *Skeletonema* frustules to identify using the updated protocols.

One outcome of this study was to identify potentially toxic or harmful phytoplankton in the 14 PEI inlets, during the late summer and fall of 2001 to 2003 (Table 14). These 19 phytoplankton could be a threat to other organisms in the ecosystem, to the aquaculture industry, or to human health. No paralytic shellfish poisoning (PSP) toxin-producing *Alexandrium tamarense* were found; these usually occur earlier in the summer, and so far only in western and southwestern PEI (J. White, CFIA, Charlottetown, PEI, pers. comm.). The only *Alexandrium* species found was the hepatotoxic *A. pseudogonyaulax* (= *Goniodoma pseudogonyaulax*). However, it was in such low numbers (maximum of 2,508 cells L^{-1} in Lennox Channel on 9-Sep-02; Appendix E4) that it posed no problems; nor is there any history of it causing problems on our waters. Below, we briefly discuss each of the other species listed in Table 14.

Table 14. Harmful and toxic phytoplankton species identified in PEI inlets during the late summer and fall of 2001–2003, and their potential or actual affects on human health other marine biota. Representative references are also given.

Species	Type	Harmful / toxic effect	Reference
Chaetoceros concavicornis	Diatom	Non-toxic; gill irritant; fish mortality	Yang and Albright 1994
Chaetoceros convolutus	Diatom	Non-toxic; gill irritant; fish mortality	Taylor 1993
Chaetoceros debilis	Diatom	Non-toxic; gill irritant; fish mortality	Bruno *et al.* 1989
Corethron criophilum	Diatom	Non-toxic; gill irritant; fish mortality	Speare *et al.* 1989
Leptocylindrus minimus	Diatom	Fish mortality	Clément and Lembeye 1993
Pseudo-nitzschia fraudulenta	Diatom	Potential cause of Amnesic Shellfish Poisoning (ASP); domoic acid	Rhodes *et al.* 1996
Pseudo-nitzschia multiseries	Diatom	Cause of ASP; domoic acid	Bates *et al.* 1998
Pseudo-nitzschia seriata	Diatom	Cause of ASP; domoic acid	Fehling *et al.* 2004
Amphidinium carterae	Dinoflagellate	Haemolysin production; fish mortality	Yasumoto *et al.* 1987
Dinophysis acuminata	Dinoflagellate	Pectinotoxin production; Potential cause of Diarrhetic Shellfish Poisoning (DSP)	Suzuki *et al.* 2006; Marcaillou *et al.* 2005
Dinophysis norvegica	Dinoflagellate	Potential cause of DSP	Larsen and Moestrup 1992
Dinophysis rotundata	Dinoflagellate	Potential cause of DSP	Lee *et al.* 1989
Gymnodinium splendens	Dinoflagellate	Toxic to larval oysters	Cardwell *et al.* 1979
Karenia mikimotoi	Dinoflagellate	Fish and benthic fauna mortality	Silke *et al.* 2005
Alexandrium pseudogonyaulax	Dinoflagelate	Hepatotoxin (goniodomin A) and antifungal effect	Terao *et al.* 1990
Prorocentrum minimum	Dinoflagellate	Detrimental effects in molluscs; toxin kills mice	Grzebyk *et al.* 1997
Dictyocha speculum	Silicoflagellate	Non-toxic; clogs fish gills; hypoxia; fish mortality	Smayda 2006
Mesodinium rubrum	Litostomate ciliate	Fish mortality	Martin and Wildish 1990
Microcystis sp.	Cyanobacterium	Microcystin toxin production	Chen *et al.* 1993

Of particular concern to the mussel aquaculture industry in PEI are certain species of the genus *Pseudo-nitzschia* (Bates 1997, 2004, 2006). For this study, the sampling period of September to December was chosen because that is when domoic-acid-producing blooms of *P. multiseries* have occurred, starting in 1987, and continuing to 1989 in eastern PEI; other closures occurred during that period in New London Bay (1991, 1992, 1994), Malpeque Bay (1991, 2001), and Mill River (2000). Fortunately for the aquaculture industry, there were no fall closures of mussel harvesting in PEI due to *P. multiseries* during the 2001 to 2003 sampling period. This is only unfortunate from a scientific viewpoint, because it did not allow us to document the conditions that lead up to a toxic *P. multiseries* bloom or to follow its decline. During 2001 to 2003, *P. multiseries* cells were found only occasionally (Fig. 11D, E) and in low proportions relative to the other non-toxic *Pseudo-nitzschia* species (Table 10); these low levels were insufficient to toxify any mussels. Reasons for the scarcity of *P. multiseries* and the dominance of the non-toxic *P. pungens* and *P. calliantha* are still elusive. The toxic blooms of 1987 to 1989 were characterized by exceedingly dry summers, followed by very rainy fall periods; this is thought to have provided nutrients, via runoff, to fuel the blooms (Bates *et al.* 1998). These meteorological conditions have not recurred, although other factors are undoubtedly also necessary for a single phytoplankton species to dominate (see below).

Laboratory studies have shown that domoic acid production is minimal or zero during rapid cell growth and high during Si deficiency when *Pseudo-nitzschia multiseries* cells cease dividing (Bates *et al.* 1998). In the field, such a condition presents itself when there is an alternation of N sufficiency, which promotes the growth of this toxigenic diatom, followed by a period of Si deficiency, when cell growth becomes Si limited. The rapidly fluctuating concentrations of N and Si, seen especially in Cardigan River in all three years (Fig. 6), can result in equally dynamic changes between N and Si deficiency (Fig. 20). Laboratory studies have also shown that toxin production requires N (Bates *et al.* 1991). Therefore, we hypothesize that in the field, cell toxicity would be low during periods of N deficiency and also during short periods of active growth, followed by high toxicity during periods of Si deficiency. In other words, had *P. multiseries* been present in high numbers, nutrient conditions could have been appropriate for toxin production. The effects of Fe deficiency on domoic acid production are still being debated (Bates and Trainer 2006).

The most abundant *Pseudo-nitzschia* species was the non-toxic *P. calliantha* (Table 8). Prior to the naming of this new species (Lundholm *et al.* 2003), we called it *P. pseudodelicatissima*. Its presence in Cardigan River in 2002, at concentrations as high as 5.33×10^6 x cells L^{-1}, and still rising (Fig. 16), caused great consternation until light microscopy confirmed that it was not the much wider toxigenic *P. multiseries*. Laboratory studies later showed that isolates did not produce domoic acid in culture; scanning electron microscopy then identified it as *P. calliantha* (Bates, unpublished). Some isolates of *P. calliantha* from elsewhere in the world have been shown to produce domoic acid (Lundholm *et al.* 2003), but none from PEI inlets.

As was the case with *Pseudo-nitzschia calliantha*, the presence of high concentrations of *P. delicatissima* (up to 2.19×10^6 cells L^{-1} on 19-Nov-01, in Cardigan River; Fig. 17) should not be considered problematic. No toxicity events were associated with high concentrations of this species in the PEI inlets. In Atlantic Canadian waters, at least, isolates of *P. delicatissima* have never been shown to produce domoic acid in culture; this includes isolates from Granville Ferry

(Bay of Fundy, NS), Ship Harbour (Atlantic coast, NS) (Bates, unpublished), and Mont-Joli (St. Lawrence Estuary, QC) (Couture *et al.* 2001). In contrast, some (but not all) strains of this species from New Zealand (Rhodes *et al.* 1996), and Denmark (Lundholm *et al.* 1997) were shown to produce low amounts of domoic acid. Similarly, all isolates of *P. fraudulenta* from Atlantic Canada have proven to be non-toxic (Bates, unpublished), although strains from New Zealand are toxigenic (Rhodes *et al.* 1996). It is common to have toxic and non-toxic strains of the same species of *Pseudo-nitzschia* (Bates *et al.* 1998; Bates and Trainer 2006).

Pseudo-nitzschia seriata was found sporadically, and only at very low concentrations, during our late summer to fall sampling period. The highest cell concentration was 880 cells L^{-1}, in Lennox Channel, on 10-Dec-01 (Appendix D4). Since this species is considered to be a cold-water diatom (Hasle 2002), it is not surprising that it was found in a mid-December sample, when the water temperature would be in the range of 2 to 5°C. However, it was also found in Cardigan River earlier in the season (4-Sep-02), as seen in a scanning electron microscopy image (Fig. 11E, F). The water temperature at that time was 19°C (Smith 2002). This indicates the ability for the PEI strain of *P. seriata* to withstand warmer temperatures, and supports Fehling *et al.* (2004, 2005), who found *P. seriata* in Scottish waters of 15°C, and who grew it successfully at that same temperature. It is not known if this species is endemic to inlets of PEI, or if was introduced from offshore waters of the southern Gulf of St. Lawrence, and remained in the inlets as a result of the major spring bloom of 2002 (Bates *et al.* 2002); nevertheless this is the first documentation of its presence in the fall, in PEI waters. It should also be pointed out that less abundant phytoplankton species, such as this *P. seriata*, may not always be detected by light microscopy because of the small volume of water placed in the Utermöhl settling chambers (50 mL; and occasionally 10 or 25 mL).

This study reports, for the first time, the presence of two new species of *Pseudo-nitzschia* in waters of the Gulf of St. Lawrence: *P. americana*, and the tentatively identified *P. subpacifica* (Table 7). These were found in very low numbers, only in Lennox Channel and New London Bay, and only in 2003. Both of these species were also reported for the first time in low numbers in the Bay of Fundy (Kaczmarska *et al.* 2005). Neither has been reported to be a domoic acid producer. *Pseudo-nitzschia fraudulenta* is reported for the first time in PEI inlets. It was previously observed in low proportions at four sites on the Northumberland Strait shore of Nova Scotia (Caribou Harbour, Wallace Harbour, Little Harbour, and Pugwash Harbour), on December 20, 2001 (Bates, unpublished observations; Carver and Mallet 2003).

We are far from being able to predict which phytoplankton species will dominate a particular bloom during a given part of the fall. It is therefore even more difficult to predict which species of *Pseudo-nitzschia*, toxigenic or not, will dominate. Cells of a particular species must first be present in the water column, either as a result of advection into the inlet or emergence of dormant stages from the sediments (so far there is no evidence that any *Pseudo-nitzschia* species forms "resting stages"). Conditions must then be optimum for that species to dominate. Nutrient ratios, and their concentrations, are but two of numerous factors that may control which species will bloom. Here we have emphasized that a species' Ks value may determine its ability to outcompete other species at low inorganic nutrient levels. Other factors that must be considered include a species' ability to grow on organic nutrients, optimum temperature and irradiance level for growth, selective predation, and physical removal from the system via sinking and advection.

Most of the remaining potentially toxic or harmful phytoplankton listed in Table 14 were found only at low concentrations or sporadically; they therefore did not cause any deleterious events, nor have they been shown to be problematic in the past. Nevertheless, it is important to be aware of their presence, because conditions may still arise that could lead to their proliferation, with resulting negative consequences.

The non-toxic diatoms *Chaetoceros concavicornis*, *C. convolutus*, and *C. debilis* are characterized by barbed setae that may irritate the gills of fish, especially farmed salmonids, leading to suffocation and eventual death (Bruno *et al.* 1989; Taylor 1993; Yang and Albright 1994). *Corethron criophilum* (= *Corethron hystrix*), another diatom, possesses a central corona of short spines tipped with small claws, which could contribute to salmonid deaths in the same way as the above *Chaetoceros* species (Speare *et al.* 1989). The chain-forming centric diatom *Leptocylindrus minimus* has been implicated in mortalities of aquacultured salmon and trout in southern Chile, but nowhere else in the world (Clément and Lembeye 1993). Concentrations above 1.0×10^7 cells L^{-1} provoked the salmon deaths, but the highest concentration found in our study was 3.1×10^5 cells L^{-1} (Lennox Channel, 10-Dec-01; Appendix D4). Because PEI inlets are used exclusively for the aquaculture of molluscan shellfish, not salmonids, the above diatoms would not be considered a problem there, especially at the low concentrations found. Wild fish that are not in cages are more likely able to escape the deleterious effects of these diatoms.

The presence of the dinoflagellate *Karenia mikimotoi* (previously called *Gyrodinium aureolum*, *Gymnodinium nagasakiense*, and *Gymnodinium mikimotoi*) should be considered as a potential threat to benthic and pelagic fauna, including molluscan shellfish used in the aquaculture industry. This dinoflagellate, found primarily in Cardigan Bay in 2001 and 2003 (Fig. 19), was identified by Dr. Gert Hansen (Biological Institute, Copenhagen, Denmark), based on formalin-acetic-acid-preserved material sent to him. Dr. Hansen is a world expert on the taxonomy of this group of organisms. However, he indicated that his identification of *K. mikimotoi* would have been more certain had the material been preserved in glutaraldehyde so that the cells could have been examined by scanning electron microscopy to look for distinguishing characteristics of the apical groove and cingular/sulcus areas of the cell (pers. comm.). Nevertheless, Murielle LeGresley (DFO, SABS), who carried out all of the other phytoplankton identifications and counts for this study, is confident about the identification (pers. comm.). This dinoflagellate is problematic because it has caused mortalities of wild and farmed fish, and benthic invertebrates, in European coastal waters. For example, there was an 80% mortality of farmed clams (*Tapes semidecussata*) during a 1992 bloom of *K. mikimotoi* in Ireland (O'Boyle *et al.* 2001). An even larger bloom in 2005 resulted in mass mortalities of aquacultured oysters (spat and adult), clams, scallops, and abalone, as well as other benthic fauna (Silke *et al.* 2005). In 1995, a *K. mikimotoi* bloom caused the mortality of 800-900 tonnes of blue mussels (*Mytilus edulis*) along the French Atlantic coast (Gentien 1998). Other blooms of *K. mikimotoi* in France caused a mass mortality of post-larval stages of the king scallop (*Pecten maximus*), stopped the growth of juvenile stages and reduced both growth and reproduction of adult scallops (Erard-Le Denn *et al.* 1990). Smayda (2006) reviewed the mortalities of fish and benthic fauna in Scottish waters, caused by this dinoflagellate. Although cytotoxic polyethers have been extracted from cultures of *K. mikimotoi*, the exact mechanism of the toxic effect remains unclear. Fish mortality may also result from hypoxia during a *K. mikimotoi* bloom (reviewed by Silke *et al.* 2005; Smayda 2006). The above studies reported cell concentrations on

the order of 10^6 cells L^{-1} during the mortality events. Such cell densities were reached in Cardigan River, in 2001 (1.54 x 10^6 cells L^{-1} on 31-Oct-01) and 2003 (1.33 x 10^6 cells L^{-1} on 20-Oct-03) (Fig. 19), yet no mortalities of any organisms were reported there. Because the identity of this species, which has many look-alikes, has not been completely clarified in our waters, it may prove to be a non-toxic variety. Its identity should be verified by molecular means and/or by scanning electron microscopy, if such blooms appear again in PEI inlets.

Methanolic extracts from European cultures of the dinoflagellate *Prorocentrum minimum* revealed a neurotoxin that rapidly killed mice when injected intraperitoneally (Grzebyk *et al.* 1997). *Prorocentrum minimum* cultures (CCMP1329) from New York did not support the growth of juvenile northern quahogs (*Mercenaria mercenaria*), was acutely toxic to juvenile bay scallops (*Argopecten irradians*) (Wikfors and Smolowitz 1993), and hindered the growth and development of oyster (*Crassostrea virginica*) larvae (Wikfors and Smolowitz 1995). In our study, *P. minimum* was found in all of the inlets, but mostly in 2002, when a maximum concentration of 1.4 x 10^5 cells L^{-1} was reached in New London Bay (17-Sep-02; Appendix E3). Because of its toxicity record, the abundance of this species should be monitored in future programs. *Prorocentrum micans*, also found during this study, is generally considered as non-toxic, although toxic blooms have been recorded from Chile and Holland (Cassie 1981); dense blooms of this dinoflagellate have been considered as "red tides". No cells of *Prorocentrum lima* were found during this study, even though it is present at mussel aquaculture sites in the Magdalen Islands, Gulf of St. Lawrence (Levasseur *et al.* 2003). However, it is an epibiont, and therefore not often found in significant numbers in the water column; its abundance also peaks in mid-summer (Levasseur *et al.* 2003). This species is of concern because it is responsible for the presence of the DSP toxins found in molluscan shellfish in Atlantic Canada (Bates 1997).

The dinoflagellates *Dinophysis acuminata* and *Dinophysis norvegica* are proven producers of DSP toxins in European waters (Larsen and Moestrup 1992; Marcaillou *et al.* 2005); *Dinophysis rotundata* strains from Japanese waters are toxic (Lee *et al.* 1989). However, there is no strong evidence that any species of *Dinophysis* is toxigenic in Atlantic Canadian waters (Cembella 1989; Bates 1997). Nevertheless, monitoring programs should still be vigilant for the presence of these species. *Amphidinium carterae* is known to cause red tide and has been implicated in the mass mortality of fish (Yasumoto *et al.* 1987). However, this dinoflagellate was not a major threat in PEI inlets during the study period, because it was found only once, and a very low concentrations (193 cells L^{-1}, on 30-Sep-03, New London Bay; Appendix F3). *Gymnodinium splendens* (also called *Gymnodinium sanguineum*), capable of colouring the water dark red, has been shown to be toxic to larval stages of two species of oysters in Puget Sound (Cardwell *et al.* 1979), and is believed to be responsible for at least one reported fish mortality event in Peru (Jordan 1979). In our study, it was reported only once, and at a very low concentration (80 cells L^{-1}, on 6-Oct-03, in Tracadie Bay; Appendix F2).

The non-toxic silicoflagellate *Dictyocha speculum* (also called *Distephanus speculum*) is found in naked and skeletal forms. The latter was identified in this study, sporadically in Cardigan River, reaching a maximum concentration of 3.5 x 10^3 cells L^{-1} on 23-Oct-02 (Appendix E1). Both forms of this organism are known to have caused kills of farmed fish by either of two mechanisms: hypoxia, due to nocturnal depletion of oxygen by high cell densities; and by piercing and abrasions of the gills, due to the spines of the siliceous skeletal form (Erard-Le Denn and Ryckaert 1990; Henriksen *et al.* 1993; reviewed by Smayda 2006).

The non-toxic ciliate *Mesodinium rubrum* (also called *Myrionecta rubra*) is capable of forming massive "red tide" blooms that can deplete oxygen levels. This has occurred in the Bay of Fundy, resulting in the mortality of caged salmon (Martin and Wildish 1990). Although this organism was found in every inlet, during 2001 to 2003, it did not reach a sufficient concentration (its maximum was 10.2 x 10^3 cells L^{-1} on 20-Nov-02, in Lennox Channel; Appendix E4) to have caused anoxia problems.

Some species of the cyanobacterium *Microcystis* produce microcystins, tumour-promoting hepatotoxins that can accumulate in molluscan shellfish and can also cause fish kills. There have been no reports of toxic marine cyanobacteria in Canadian waters. However, Chen *et al.* (1993) identified microcystin-LR, the toxin normally associated with the *Microcystis*, in mussels collected in 1991 from New London Bay. *Microcystis* sp. was present only in low numbers, and only in Lennox Channel, in early September 2002 (Appendix E4) and 2003 (Appendix F4).

Of the 124 species of phytoplankton listed in our study (Table 7), 11 have apparently never before been reported in the Gulf of St. Lawrence (Table 15). Bérard-Therriault *et al.* (1999) provide a comprehensive identification guide of marine phytoplankton in the estuary and Gulf of St. Lawrence. However, they did not include benthic diatom species; therefore, the benthic centrics *Actinoptychus senarius* and *Melosira monoliformis* were not listed; they are reported in Bérard-Therriault *et al.* (1987). The following benthic pennate diatoms are also documented elsewhere: *Striatella unipunctata* (Poulin *et al.* 1984); *Gyrosigma balticum* and *Gyrosigma tenuissimum* (Cardinal *et al.* 1986). The dinoflagellate *Alexandrium pseudogonyaulax* was first observed in the Magdalen Islands and at Tête-à-la-Baleine in 2001 (E. Bonneau, DFO, Mont-Joli, QC, pers. comm.), after the Bérard-Therriault *et al.* (1999) guide was published. It should be pointed out that none of these authors sampled in any inlets of PEI, so it is possible that they missed those species if they grew exclusively in that habitat. Likewise, the rarer species may not have been detected. One must also consider the possibility that some of these species could have been introduced into Gulf of St. Lawrence waters. In the case of *Pseudo-nitzschia fraudulenta*, there is some evidence that it may have been introduced via ballast waters to inlets of northern Nova Scotia (Carver and Mallet 2003). This study points out the importance of continuing to compile phytoplankton species lists, over a period of several years, in order to look for species that have never before appeared in our waters. It would also be important to sample year round.

Table 15. Phytoplankton species found in our study (from Table 7), but apparently not reported elsewhere in the literature for the Gulf of St. Lawrence.

Centric Diatoms	Pennate diatoms	Dinoflagellates
Guinardia flaccida	*Grammatophora marina*	*Gymnodinium splendens*
Guinardia striata	*Gyrosigma littorale*	*Polykrikos* cf. *kofoidii*
Paralia marina	*Pleurosigma angulatum*	
	Pseudo-nitzschia americana	
	Pseudo-nitzschia fraudulenta	
	Pseudo-nitzschia cf. *subpacifica*	

CONCLUSIONS

There is a perception that coastal inlets are eutrophic. In the case of some PEI inlets, previous studies have used the presence of dense blooms of sea lettuce (*Ulva lactuca*) as evidence of eutrophication. However, our study of 14 inlets shows generally low concentrations of the major inorganic nutrients during the late summer and fall. It should be pointed out that our conclusions should not be extrapolated beyond the seasons during which observations were made. Based on a comparison of ambient nutrient concentrations with the inherent ability of the phytoplankton to take up the nutrients at low concentrations, we conclude that these low nutrient levels, often more than one nutrient at a time, may limit the growth of phytoplankton in these inlets. Furthermore, a comparison of nutrient ratios shows that the carrying capacity of diatoms and of dinoflagellates may also be limited by nutrients.

Inorganic nitrogen (N) was dominated by NH_3 (mean value = 2.23 μM), with lower values of NO_3 (0.64 μM) and NO_2 (0.118 μM). The mean total inorganic N was only 3.22 μM, a value well below that thought to indicate eutrophication. Silicate and phosphate levels were also low most of the time, with mean values of 1.20 and 0.45 μM, respectively.

These N and Si concentrations were generally below those believed to limit rates of nutrient uptake and growth of phytoplankton. Nutrient conditions in which two or three nutrients are simultaneously at limiting levels occur frequently in the fall in PEI inlets. On the basis of a proposed model of nutrient co-limitation, we have calculated that diatom growth was limited by Si in 72% of the samples collected and by a combination of low N and low P in the other 28%. Furthermore, the nutrient(s) limiting diatom growth in an inlet can be quite variable. For example, in Cardigan River in 2001 and 2002, N+P limited growth early in the season, but Si became limiting later in the season. Although the details of these predictions are subject to the limitations of the assumed model for co-limitation and the values for Ks used, they do show the potential influence of co-limitation and the need for a better understanding of these processes for understanding species composition, abundance, and succession of coastal marine phytoplankton. Such understanding will require culture studies conducted with multiple nutrients at limiting concentrations.

The limitation of carrying capacity for phytoplankton was also examined. This is fundamentally different from the limitation of growth rates or of ambient biomass. Diatom carrying capacity, determined from Redfield ratios, was limited by Si in 75% of samples, by N in 21% and by P in 4%; dinoflagellate carrying capacity was limited by N in 74% of the samples and by P in 26%. Again, patterns of limitation varied between inlets and between years.

Some significant statistical relationships between nutrients and the phytoplankton community were identified. Five distinct groups of inlets/years were identified by a cluster analysis of the nutrient data. The phytoplankton communities in these groups are clearly more similar in species abundance and species composition to each other than are phytoplankton communities from different groups. A correlation analysis between nutrients and abundance measures of the phytoplankton community found negative correlations between phytoplankton and the concentrations of inorganic nitrogen. Such a relationship implies that nitrogen is more rapidly

turned over by phytoplankton growth and decay in these inlets than by other processes, such as physical mixing.

Of the 124 distinct species of phytoplankton identified for all inlets studied during 2001-2003, the major groups consisted of 49 centric diatoms, 27 pennate diatoms, and 36 dinoflagellates. The diatom *Skeletonema costatum* was the most abundant species. Nineteen potentially toxic or harmful species were recorded, but their numbers were generally too low to have caused any shellfish harvesting closures or environmental harm during the sampling period. The toxic dinoflagellate *Karenia mikimotoi*, however, was abundant in Cardigan River during October 2001 and 2003, but no harmful effects were observed. The domoic-acid-producing diatom *Pseudo-nitzschia multiseries* was infrequently found, and only in low numbers. Other species of *Pseudo-nitzschia*, including the non-toxic *P. calliantha*, *P. pungens*, and *P. delicatissima*, bloomed in its place. Two new species of *Pseudo-nitzschia* (*P. americana* and the tentatively identified *P. subpacifica*) were reported for the first time in the Gulf of St. Lawrence. *Pseudo-nitzschia fraudulenta* was found for the first time in PEI inlets. Eleven species of phytoplankton have apparently never before been recorded in the Gulf of St. Lawrence.

During all three years, Tracadie Bay exhibited an order of magnitude lower number of total phytoplankton cells than did Cardigan River; Lennox Channel and New London Bay showed intermediate values. More data are required to explain this finding, but we calculated that Tracadie Bay had a greater percentage of harvesting lease area coverage (37%) than did Cardigan River (20%). This study points out the importance of continuing to compile phytoplankton species lists over time, in order to look for toxic species, species that have never before been identified in our waters, as well as to better understand phytoplankton dynamics.

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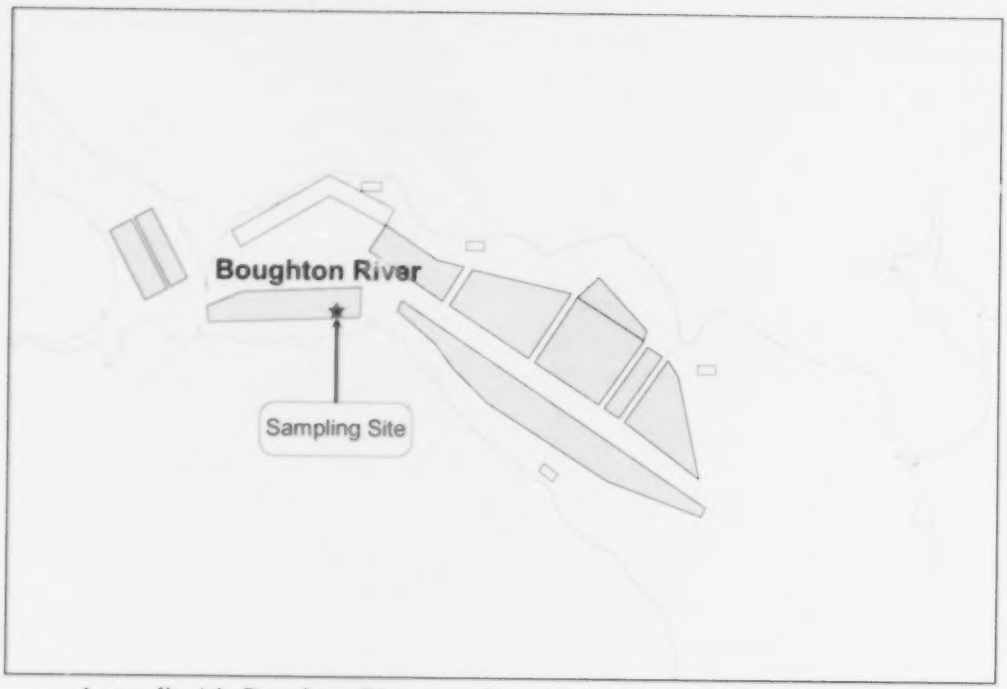
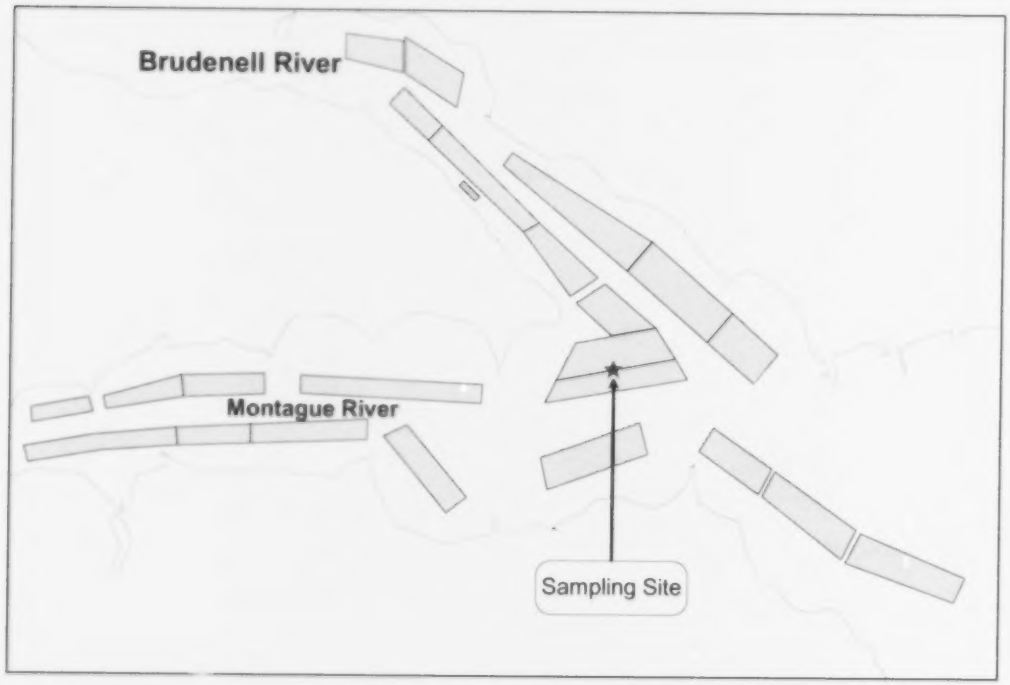
APPENDICES

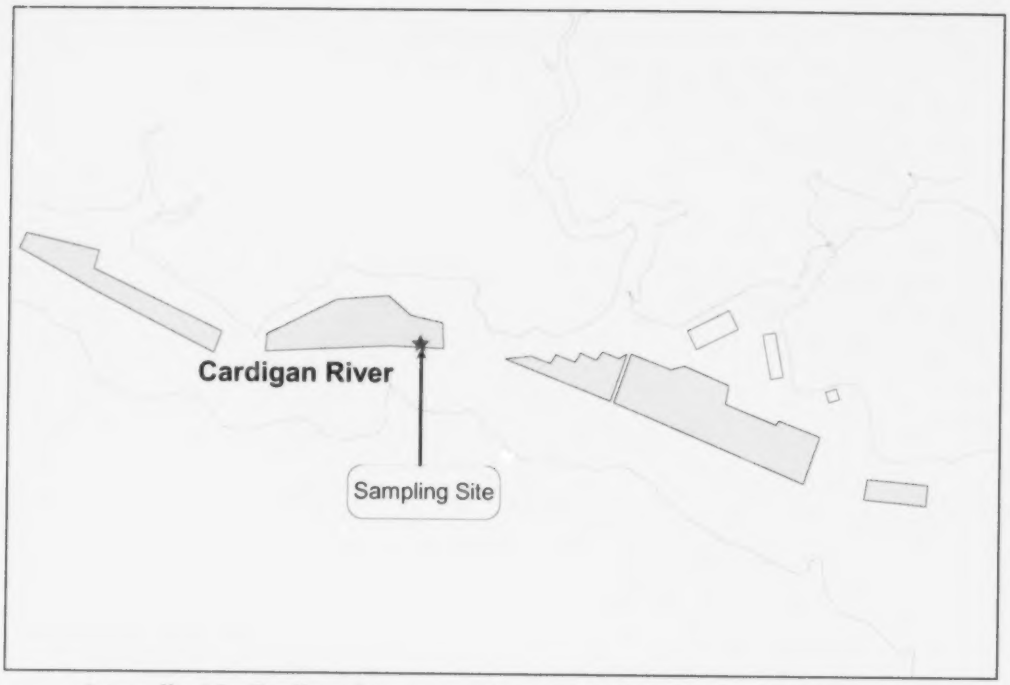
Appendix A. Prince Edward Island sampling sites for water used for nutrient and phytoplankton analyses. These correspond to the PEI Mussel Monitoring Program (MMP) sampling sites; samples collected by the Canadian Food Inspection Agency and the PEI Department of Agriculture, Fisheries and Aquaculture. Lease sites are also shown; the purple leases (shown in black and white as dark grey) are for surface culture (mussels), and the yellow leases (shown in black and white as light grey) are for bottom culture (oysters or clams). Not all leases are fully used all of the time. Maps adapted from the PEI Mussel Monitoring Program reports (Smith 2003).



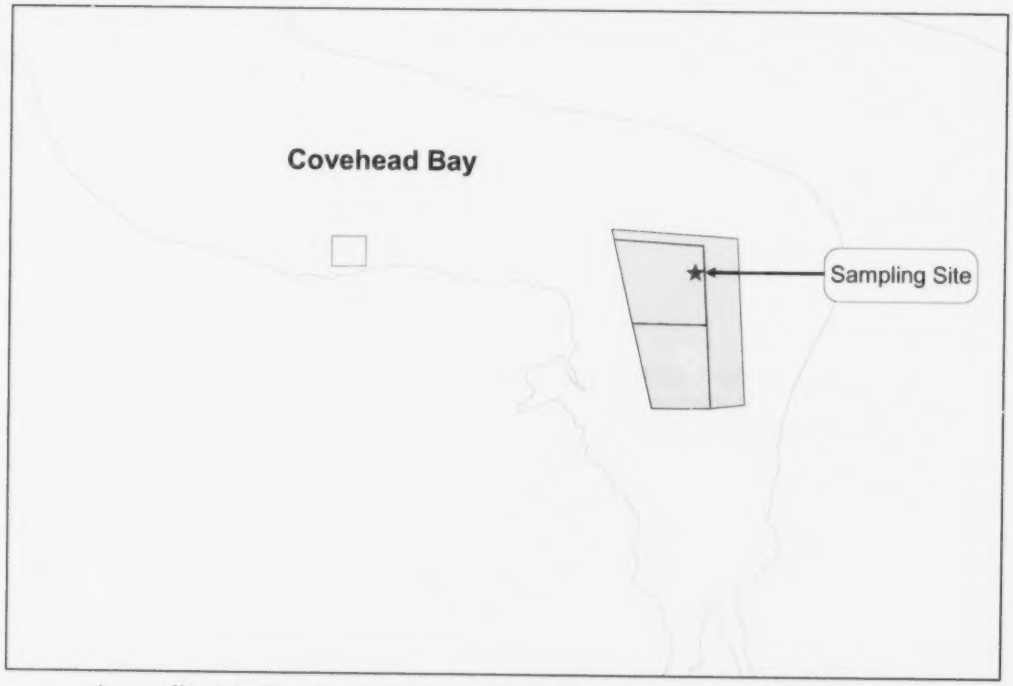
Appendix A1. Boughton River sampling site (46° 16.08' N; 62° 29.10' W).



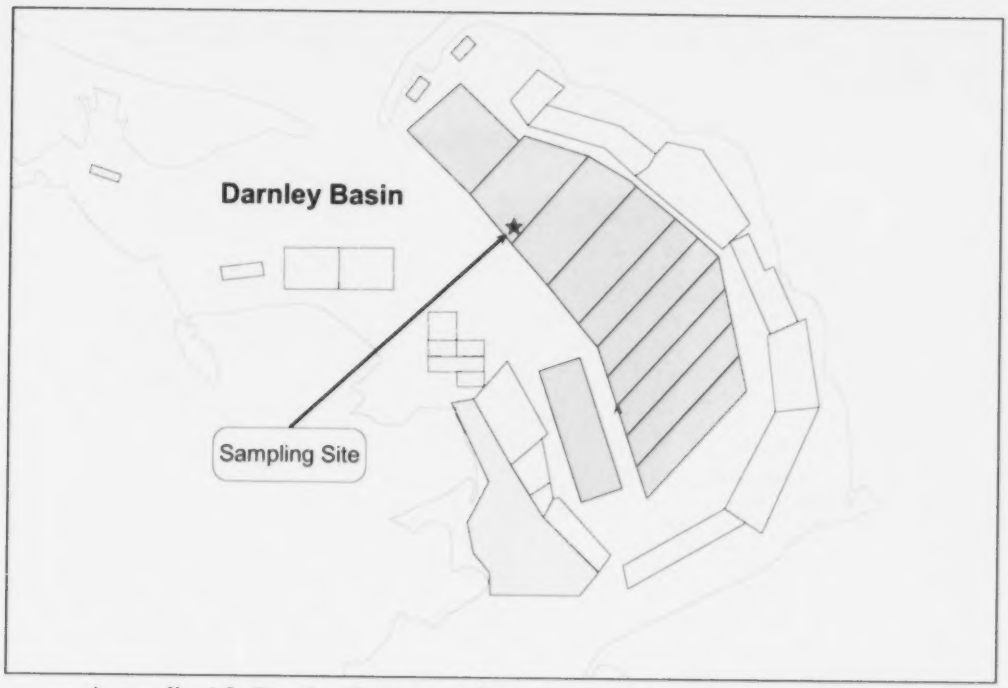
Appendix A2. Brudenell River sampling site (46° 12.12' N; 62° 36.66' W).



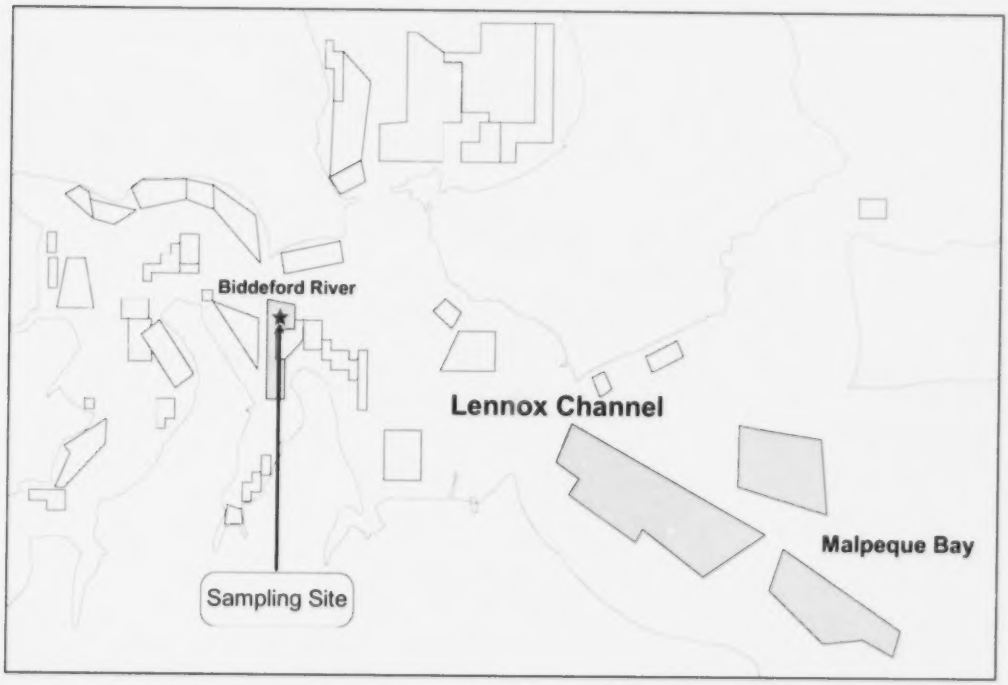
Appendix A3. Cardigan River sampling site (46° 13.44' N; 62° 34.08' W).



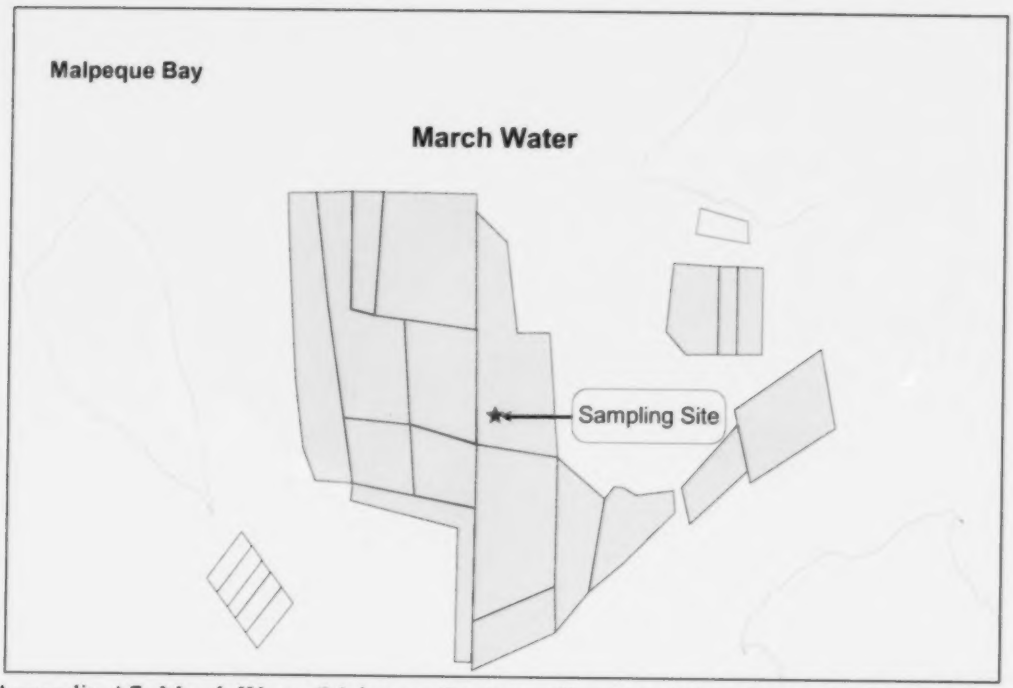
Appendix A4. Covehead Bay sampling site (46° 25.02' N; 63° 8.34' W).



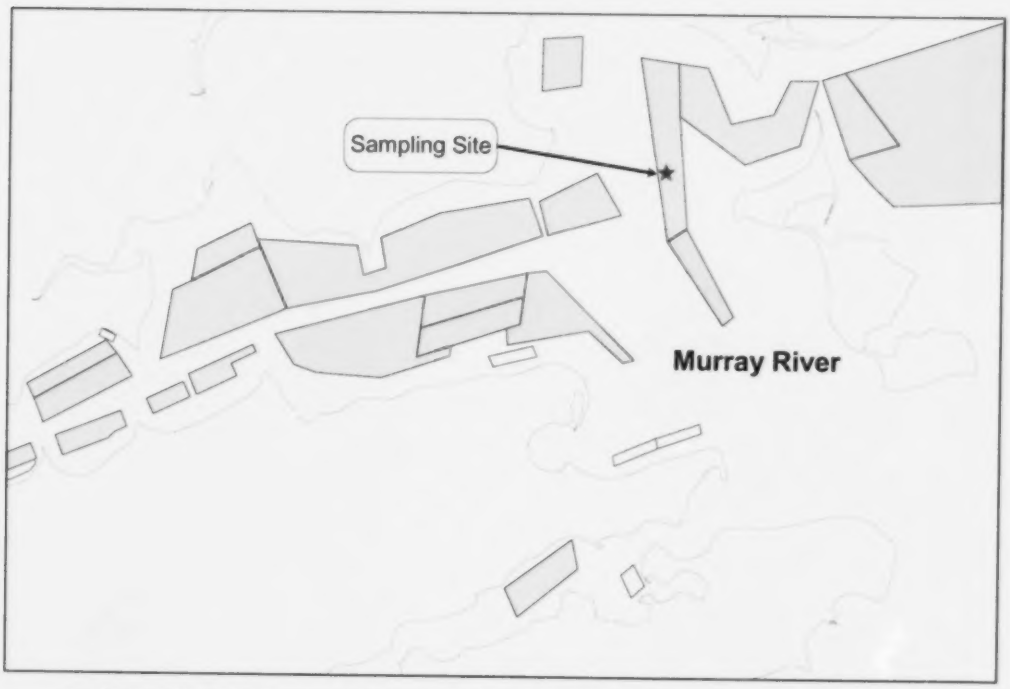
Appendix A5. Darnley Basin sampling site (46° 33.18' N; 63° 40.02' W).



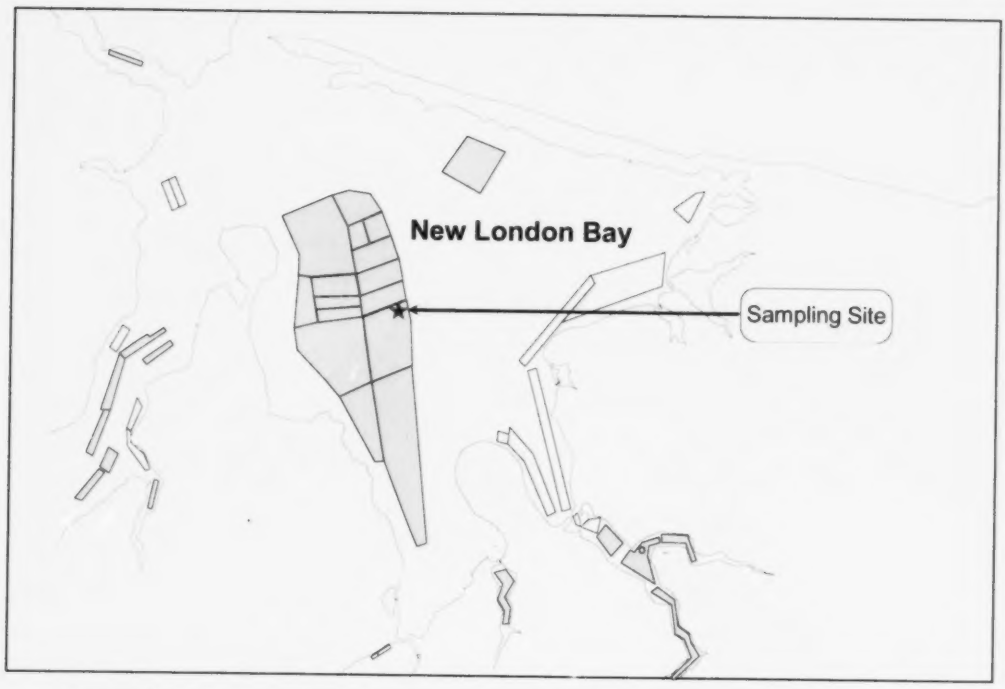
Appendix A6. Lennox Channel (Malpeque Bay) sampling site (46° 36.30' N; 63° 52.98' W).



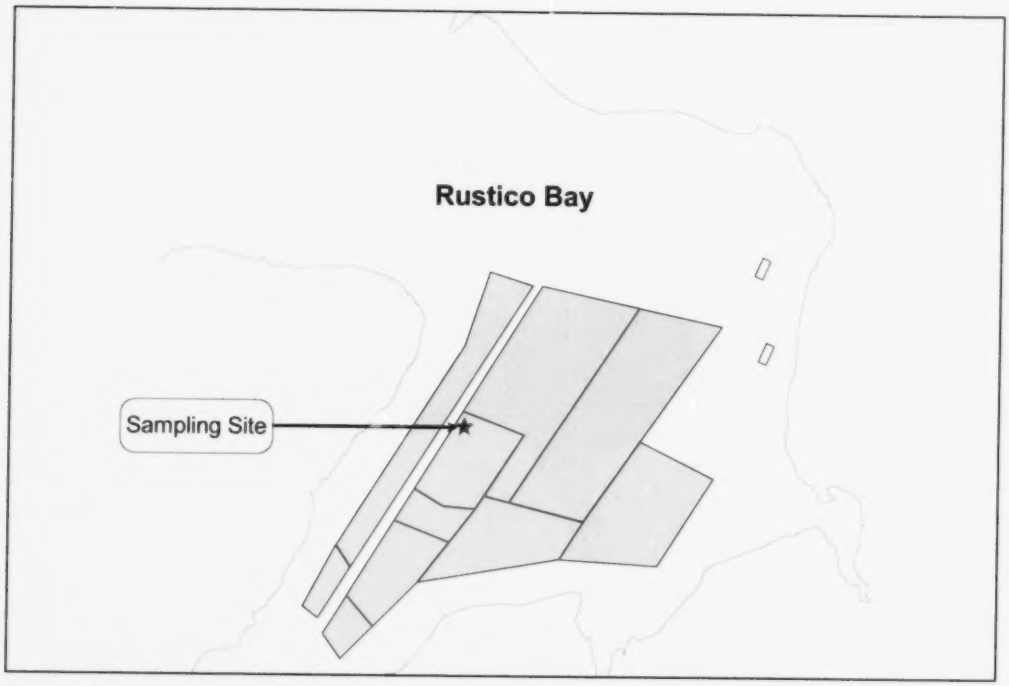
Appendix A7. March Water (Malpeque Bay) sampling site (46° 31.20' N; 63° 42.00' W).



Appendix A8. Murray River sampling site (46° 2.46' N; 62° 31.92' W).

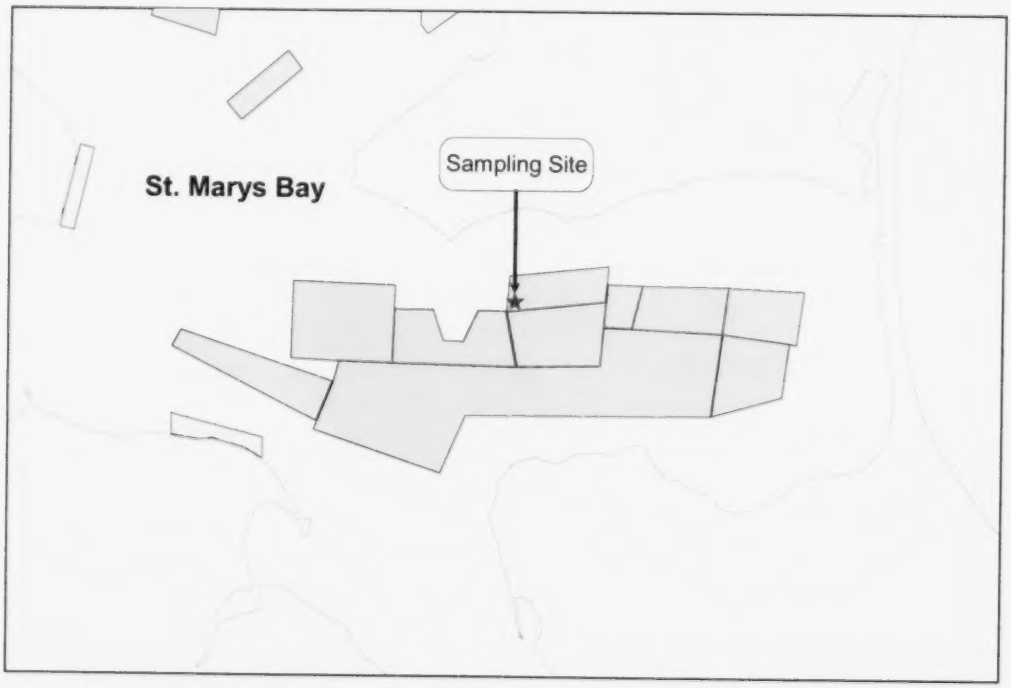


Appendix A9. New London Bay sampling site (46° 29.46' N; 63° 27.96' W).

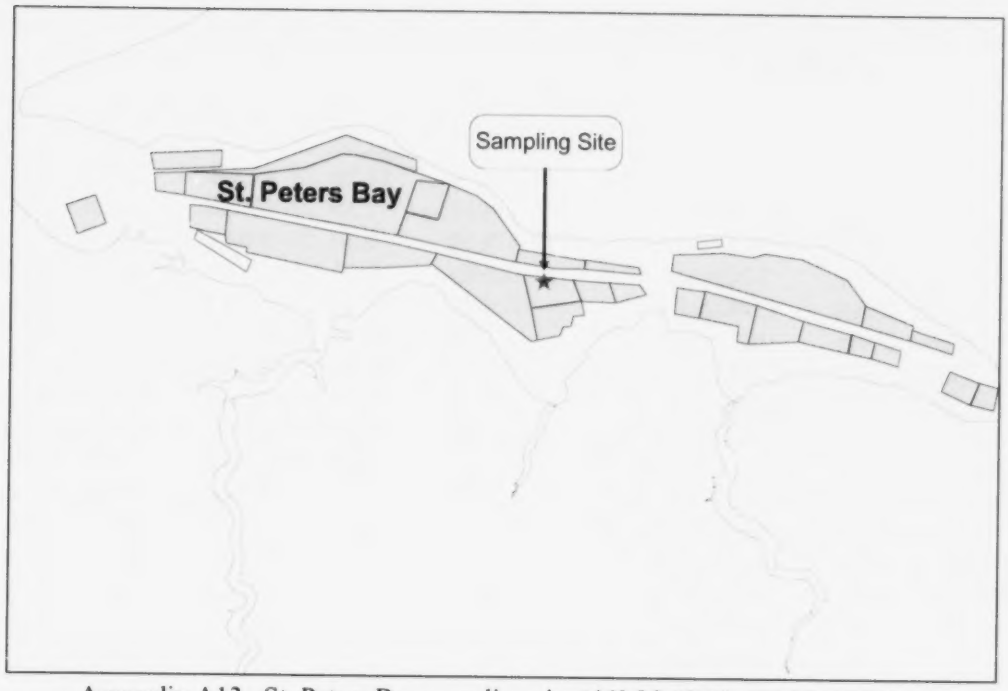


Appendix A10. Rustico Bay sampling site (46° 25.32' N; 63° 13.98' W).

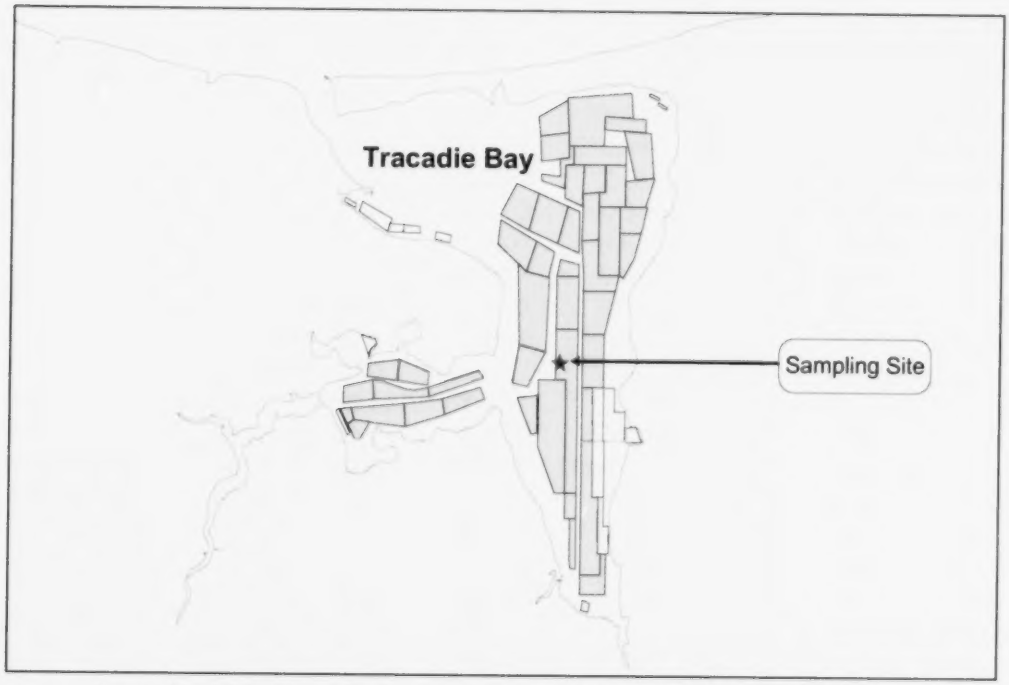
Appendix A11. Savage Harbour sampling site (46° 24.54' N; 62° 51.30' W).



Appendix A12. St. Marys Bay sampling site (46° 7.80' N; 62° 30.84' W).



Appendix A13. St. Peters Bay sampling site (46° 25.62' N; 62° 39.24' W).



Appendix A14. Tracadie Bay sampling site (46° 22.92' N; 63° 1.68' W).

Appendix B. Nutrient data, all inlets and years. All concentrations in micromoles per litre (μM). Times are local: Atlantic Daylight Time or Atlantic Standard Time.

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
Boughton River	26-Sep-01		0.39	27.26	0.208	2.80	0.656
Boughton River	12-Oct-01		0.11	7.36	0.087	3.28	0.750
Boughton River	31-Oct-01		1.12	1.54	0.544	3.35	0.526
Boughton River	7-Nov-01		0.66	2.59	0.138	0.90	0.236
Boughton River	13-Nov-01		1.15	2.49	0.108	1.71	0.291
Boughton River	19-Nov-01		2.69	1.43	0.133	1.72	0.359
Boughton River	26-Nov-01		0.61	56.20	0.123	0.00	0.187
Boughton River	3-Dec-01		1.22	4.97	0.221	0.70	0.225
Boughton River	10-Dec-01		0.46	1.49	0.156	0.48	0.227
Boughton River	17-Dec-01		2.24	2.22	0.102	1.52	0.170
Boughton River	4-Sep-02		0.55	2.77	0.152	3.04	1.476
Boughton River	9-Sep-02		0.28	0.89	0.071	2.43	0.939
Boughton River	16-Sep-02		0.27	1.02	0.066	0.26	0.641
Boughton River	23-Sep-02		0.16	1.02	0.068	2.31	0.757
Boughton River	8-Oct-02		0.44	2.55	0.104	2.79	0.470
Boughton River	21-Oct-02		0.37	1.31	0.072	0.38	0.258
Boughton River	28-Oct-02		2.74	1.82	0.218	2.97	0.295
Boughton River	6-Nov-02		7.58	1.68	0.258	2.76	0.219
Boughton River	12-Nov-02		0.82	1.85	0.145	0.38	0.315
Boughton River	18-Nov-02		5.64	0.46	0.163	2.41	0.245
Boughton River	26-Nov-02		0.99	1.27	0.099	0.16	0.271
Boughton River	15-Sep-03		0.86	4.80	0.156	3.09	0.403
Boughton River	23-Sep-03		1.55	1.18	0.090	1.37	0.376
Boughton River	1-Oct-03		0.18	0.87	0.079	1.04	0.362
Boughton River	8-Oct-03		0.12	0.90	0.065	3.29	0.499
Boughton River	14-Oct-03		0.49	0.82	0.088	2.66	0.259
Boughton River	20-Oct-03		0.29	1.40	0.086	0.42	0.313
Boughton River	27-Oct-03		0.44	2.45	0.102	2.22	0.279
Boughton River	3-Nov-03		3.58	1.40	0.156	4.16	0.255
Brudenell River	4-Oct-01		0.00	2.34	0.051	0.63	0.617
Brudenell River	10-Oct-01		0.00	0.68	0.061	0.94	0.738
Brudenell River	23-Oct-01		1.07	14.90	0.127	7.59	0.608
Brudenell River	29-Oct-01		0.78	52.62	0.246	4.55	0.587
Brudenell River	5-Nov-01	10:52	0.69	2.43	0.099	0.97	0.348
Brudenell River	13-Nov-01		0.65	13.09	0.116	0.00	0.342
Brudenell River	19-Nov-01		2.90	4.06	0.117	0.75	0.283
Brudenell River	26-Nov-01		2.07	5.11	0.131	0.00	0.271
Brudenell River	3-Dec-01		1.35	3.73	0.101	0.01	0.359
Brudenell River	10-Dec-01		1.78	1.41	0.106	0.42	0.487
Brudenell River	17-Dec-01		2.27	8.49	0.162	0.80	0.363
Brudenell River	4-Sep-02		0.55	1.24	0.081	4.01	0.806
Brudenell River	9-Sep-02		1.14	1.85	0.128	5.91	0.883

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
Brudenell River	16-Sep-02		0.40	1.97	0.096	0.45	0.475
Brudenell River	23-Sep-02		0.04	0.92	0.056	0.10	0.292
Brudenell River	8-Oct-02		0.71	3.19	0.109	6.21	0.481
Brudenell River	21-Oct-02		3.87	1.51	0.124	0.65	0.189
Brudenell River	28-Oct-02		0.66	1.29	0.086	1.45	0.188
Brudenell River	6-Nov-02		0.48	1.36	0.126	0.70	0.231
Brudenell River	12-Nov-02		14.07	2.38	0.317	4.09	0.208
Brudenell River	18-Nov-02		0.63	0.78	0.097	0.03	0.407
Brudenell River	26-Nov-02		9.96	2.51	0.285	4.97	0.172
Brudenell River	15-Sep-03		0.20	4.85	0.143	0.25	0.347
Brudenell River	23-Sep-03		1.50	1.48	0.095	1.26	0.476
Brudenell River	1-Oct-03		0.14	0.80	0.061	1.97	0.402
Brudenell River	8-Oct-03		0.10	0.74	0.058	8.49	0.647
Brudenell River	14-Oct-03		0.08	0.42	0.059	4.29	0.348
Brudenell River	20-Oct-03		0.30	1.03	0.070	1.09	0.300
Brudenell River	27-Oct-03		1.48	0.96	0.110	1.68	0.308
Brudenell River	3-Nov-03		1.31	2.95	0.125	1.61	0.329
Cardigan River	26-Sep-01		0.03	3.62	0.050	1.03	0.587
Cardigan River	4-Oct-01		0.00	0.96	0.029	6.51	0.752
Cardigan River	10-Oct-01		1.03	24.14	0.075	1.08	0.751
Cardigan River	24-Oct-01		0.00	0.48	0.045	9.42	1.122
Cardigan River	31-Oct-01		0.27	48.33	0.246	9.89	0.763
Cardigan River	5-Nov-01	11:30	0.00	1.23	0.045	7.49	0.551
Cardigan River	13-Nov-01		0.51	36.53	0.177	1.50	0.273
Cardigan River	19-Nov-01		0.72	0.98	0.037	0.54	0.292
Cardigan River	26-Nov-01		0.60	92.09	0.066	0.02	0.361
Cardigan River	3-Dec-01		1.03	1.99	0.106	0.18	0.365
Cardigan River	10-Dec-01		0.60	2.78	0.106	0.53	0.342
Cardigan River	17-Dec-01		2.32	100.30	0.142	1.46	0.392
Cardigan River	4-Sep-02		1.07	4.62	0.231	7.63	1.509
Cardigan River	9-Sep-02		0.33	0.80	0.079	3.67	0.767
Cardigan River	16-Sep-02		0.45	2.02	0.074	1.66	0.772
Cardigan River	23-Sep-02		0.46	3.83	0.099	5.29	0.636
Cardigan River	8-Oct-02		0.17	2.32	0.072	4.65	0.675
Cardigan River	21-Oct-02		0.34	3.30	0.094	0.84	0.217
Cardigan River	28-Oct-02		0.53	0.81	0.055	0.47	0.249
Cardigan River	6-Nov-02		0.46	1.61	0.101	1.18	0.429
Cardigan River	12-Nov-02		3.41	0.75	0.149	0.00	0.365
Cardigan River	18-Nov-02		2.46	1.48	0.183	1.85	0.240
Cardigan River	26-Nov-02		0.71	1.83	0.112	2.26	0.463
Cardigan River	15-Sep-03		0.15	1.32	0.089	1.02	0.391
Cardigan River	23-Sep-03		1.45	2.59	0.088	3.67	0.919
Cardigan River	1-Oct-03		0.16	1.16	0.123	1.04	0.393
Cardigan River	8-Oct-03		0.10	0.97	0.069	6.61	0.677
Cardigan River	14-Oct-03		0.13	0.72	0.086	7.64	0.356

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
Cardigan River	20-Oct-03		0.22	1.37	0.071	3.79	0.405
Cardigan River	27-Oct-03		9.80	0.52	0.063	5.36	0.325
Cardigan River	3-Nov-03		0.35	0.84	0.067	0.47	0.204
Covehead Bay	10-Oct-01	14:00	0.97	14.13	0.252	0.81	0.189
Covehead Bay	25-Oct-01	13:25	0.28	2.35	0.098	0.05	0.212
Covehead Bay	15-Nov-01	10:20	2.66	4.04	0.170	1.28	0.248
Covehead Bay	27-Nov-01	12:30	6.06	3.07	0.240	2.50	0.381
Covehead Bay	3-Sep-02		0.38	2.34	0.107	3.59	1.190
Covehead Bay	10-Sep-02		0.36	0.86	0.101	2.43	1.305
Covehead Bay	17-Sep-02		0.36	0.88	0.087	0.44	0.530
Covehead Bay	25-Sep-02		0.00	0.94	0.048	0.52	0.375
Covehead Bay	9-Oct-02		0.48	3.95	0.114	2.10	0.346
Covehead Bay	23-Oct-02		0.45	1.47	0.070	4.84	0.567
Covehead Bay	31-Oct-02		1.44	1.04	0.095	0.39	0.438
Covehead Bay	4-Nov-02		0.36	0.52	0.076	0.00	0.339
Covehead Bay	13-Nov-02		4.20	2.70	0.326	4.64	0.236
Covehead Bay	10-Sep-03		0.25	0.85	0.067	0.27	0.243
Covehead Bay	25-Sep-03		0.71	0.83	0.177	0.34	0.305
Covehead Bay	30-Sep-03		1.48	1.71	0.085	1.91	0.264
Covehead Bay	6-Oct-03		3.91	1.34	0.113	0.91	0.345
Covehead Bay	15-Oct-03		1.64	1.32	0.104	0.77	0.234
Covehead Bay	22-Oct-03		2.33	3.49	0.124	2.04	0.343
Covehead Bay	29-Oct-03		2.01	4.80	0.182	3.78	0.314
Covehead Bay	5-Nov-03		6.25	6.78	0.270	5.97	0.248
Darnley Basin	11-Oct-01	10:30	0.08	1.73	0.084	0.77	0.428
Darnley Basin	23-Oct-01	11:30	0.71	22.88	0.415	0.29	0.255
Darnley Basin	29-Oct-01	11:05	0.39	2.38	0.105	0.46	0.411
Darnley Basin	5-Nov-01	10:10	0.75	2.95	0.163	0.49	0.358
Darnley Basin	13-Nov-01	9:30	0.69	3.45	0.202	0.49	0.262
Darnley Basin	19-Nov-01	10:45	3.35	4.25	0.287	2.47	0.493
Darnley Basin	26-Nov-01	12:15	4.78	3.87	0.309	2.32	0.483
Darnley Basin	4-Dec-01	10:10	1.81	1.94	0.130	0.41	0.418
Darnley Basin	10-Dec-01	10:35	0.82	2.57	0.213	0.00	0.161
Darnley Basin	3-Sep-02		0.13	1.82	0.121	0.57	0.816
Darnley Basin	9-Sep-02		0.12	2.15	0.062	1.26	0.885
Darnley Basin	17-Sep-02		0.66	5.42	0.186	1.48	0.579
Darnley Basin	23-Sep-02		0.21	2.64	0.159	0.41	0.423
Darnley Basin	1-Oct-02		0.14	1.15	0.076	0.91	0.484
Darnley Basin	9-Oct-02		0.28	2.04	0.151	0.57	0.494
Darnley Basin	16-Oct-02		0.46	1.19	0.108	0.82	0.429
Darnley Basin	21-Oct-02		0.52	4.03	0.339	0.29	0.632
Darnley Basin	28-Oct-02		0.80	2.19	0.183	0.51	0.489
Darnley Basin	4-Nov-02		1.72	2.66	0.166	0.94	0.466
Darnley Basin	12-Nov-02		2.11	2.67	0.162	0.81	0.461
Darnley Basin	20-Nov-02		6.05	3.90	0.265	2.25	0.663

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
Darnley Basin	26-Nov-02		4.97	4.86	0.243	2.19	0.583
Darnley Basin	15-Sep-03		0.08	2.74	0.092	0.85	0.920
Darnley Basin	22-Sep-03		0.14	1.68	0.076	1.96	0.942
Darnley Basin	30-Sep-03		0.13	2.44	0.088	3.89	1.072
Darnley Basin	6-Oct-03		0.20	2.31	0.072	1.53	0.906
Darnley Basin	14-Oct-03		0.17	3.42	0.135	1.18	0.551
Darnley Basin	20-Oct-03		0.39	4.36	0.173	2.07	0.559
Darnley Basin	27-Oct-03		0.78	2.67	0.114	2.57	0.560
Darnley Basin	3-Nov-03		1.43	5.67	0.183	4.74	0.593
Darnley Basin	10-Nov-03		1.29	4.20	0.180	2.84	0.539
Darnley Basin	17-Nov-03		2.23	4.02	0.201	2.60	0.491
Darnley Basin	24-Nov-03		2.64	6.11	0.252	4.07	0.652
Darnley Basin	3-Dec-03		1.70	3.48	0.202	2.34	0.533
Lennox Channel	11-Oct-01	13:05	0.04	2.13	0.083	0.29	0.442
Lennox Channel	19-Oct-01	11:30	0.20	2.62	0.082	0.38	0.423
Lennox Channel	23-Oct-01	13:05	0.03	1.17	0.065	0.12	0.345
Lennox Channel	5-Nov-01	12:00	0.06	2.46	0.104	0.04	0.258
Lennox Channel	14-Nov-01	10:00	0.37	1.67	0.104	0.13	0.309
Lennox Channel	21-Nov-01	11:20	0.93	0.95	0.115	0.38	0.255
Lennox Channel	26-Nov-01	10:30	0.17	1.04	0.068	0.40	0.209
Lennox Channel	4-Dec-01	12:25	0.17	3.77	0.299	0.05	0.184
Lennox Channel	10-Dec-01	12:25	0.03	0.53	0.046	0.00	0.157
Lennox Channel	3-Sep-02		0.07	0.84	0.055	7.72	1.265
Lennox Channel	9-Sep-02		0.07	0.70	0.056	0.61	1.046
Lennox Channel	17-Sep-02		0.09	2.48	0.064	0.33	0.329
Lennox Channel	23-Sep-02		0.06	0.21	0.046	0.81	0.528
Lennox Channel	1-Oct-02		0.06	0.24	0.047	0.28	0.490
Lennox Channel	9-Oct-02		0.07	1.08	0.140	0.14	0.467
Lennox Channel	16-Oct-02		0.14	0.19	0.051	0.07	0.458
Lennox Channel	21-Oct-02		0.10	0.95	0.099	0.02	0.460
Lennox Channel	28-Oct-02		0.23	1.56	0.121	0.12	0.585
Lennox Channel	4-Nov-02		0.34	1.17	0.185	0.08	0.476
Lennox Channel	12-Nov-02		0.68	0.88	0.127	0.18	0.380
Lennox Channel	20-Nov-02		4.41	2.29	0.240	8.03	0.431
Lennox Channel	15-Sep-03		0.03	0.14	0.063	0.52	0.453
Lennox Channel	22-Sep-03		0.06	0.59	0.081	1.68	0.614
Lennox Channel	30-Sep-03		0.07	0.62	0.085	1.34	0.657
Lennox Channel	6-Oct-03		0.05	0.47	0.073	0.77	0.540
Lennox Channel	14-Oct-03		0.16	1.63	0.073	1.58	0.438
Lennox Channel	20-Oct-03		0.26	1.22	0.109	2.11	0.388
Lennox Channel	27-Oct-03		0.32	1.63	0.103	1.71	0.263
Lennox Channel	3-Nov-03		0.27	1.60	0.123	1.70	0.405
Lennox Channel	10-Nov-03		0.34	1.40	0.083	1.09	0.354
Lennox Channel	17-Nov-03		0.12	1.67	0.062	0.92	0.396
Lennox Channel	24-Nov-03		0.09	1.15	0.081	1.33	0.277

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
Lennox Channel	3-Dec-03		0.13	0.29	0.051	0.87	0.306
March Water	5-Nov-01	11:30	0.25	17.08	0.246	0.36	0.982
March Water	14-Nov-01	10:35	0.60	2.31	0.149	0.17	0.385
March Water	9-Sep-02		0.18	2.06	0.161	0.95	1.525
March Water	9-Oct-02		0.21	1.51	0.100	0.29	1.129
March Water	16-Oct-02		0.08	0.67	0.047	0.10	0.977
March Water	15-Sep-03		0.04	0.32	0.053	0.45	0.836
March Water	22-Sep-03		0.07	1.64	0.066	1.06	1.446
March Water	30-Sep-03		0.06	0.83	0.113	0.92	1.135
March Water	7-Oct-03		0.07	0.50	0.062	0.67	1.627
March Water	3-Nov-03		0.40	2.13	0.098	1.47	0.825
Murray River	4-Oct-01		0.03	1.26	0.067	2.45	0.773
Murray River	10-Oct-01		0.10	1.31	0.086	3.57	0.564
Murray River	23-Oct-01		0.47	31.68	0.137	3.09	0.404
Murray River	29-Oct-01		0.44	7.01	0.173	3.69	0.565
Murray River	5-Nov-01		0.20	2.27	0.081	3.22	0.436
Murray River	13-Nov-01		0.90	3.15	0.112	3.11	0.468
Murray River	19-Nov-01		2.04	1.99	0.110	3.19	0.390
Murray River	26-Nov-01		0.73	3.02	0.129	2.33	0.408
Murray River	3-Dec-01		0.85	4.28	0.148	3.31	0.597
Murray River	10-Dec-01		1.00	5.33	0.171	4.05	0.644
Murray River	17-Dec-01		2.99	5.70	0.243	5.54	0.624
Murray River	4-Sep-02		1.75	0.68	0.088	2.45	1.275
Murray River	9-Sep-02		0.42	2.61	0.115	3.98	0.549
Murray River	16-Sep-02		2.25	3.52	0.226	5.65	0.936
Murray River	23-Sep-02		0.08	1.40	0.050	0.42	0.436
Murray River	8-Oct-02		0.46	3.23	0.068	0.53	0.295
Murray River	21-Oct-02		0.93	1.39	0.066	3.96	0.462
Murray River	28-Oct-02		4.15	1.89	0.163	0.72	0.185
Murray River	5-Nov-02		0.34	0.94	0.062	2.29	0.496
Murray River	12-Nov-02		0.52	0.61	0.085	0.00	0.234
Murray River	18-Nov-02		2.67	1.21	0.119	1.74	0.266
Murray River	15-Sep-03		0.12	0.55	0.068	3.22	0.781
Murray River	23-Sep-03		1.17	0.57	0.063	3.06	0.729
Murray River	1-Oct-03		0.32	1.00	0.075	5.80	0.836
Murray River	8-Oct-03		0.07	0.99	0.062	6.04	0.742
Murray River	14-Oct-03		0.09	1.00	0.054	4.42	0.506
Murray River	20-Oct-03		0.13	0.44	0.059	0.19	0.220
Murray River	27-Oct-03		0.87	4.07	0.132	9.17	0.549
Murray River	3-Nov-03		1.80	2.20	0.182	9.61	0.591
New London Bay	9-Oct-01	14:00	0.00	1.66	0.062	0.17	0.233
New London Bay	19-Oct-01	13:05	0.28	12.79	0.189	0.51	0.184
New London Bay	25-Oct-01	12:15	0.05	0.54	0.062	0.00	0.241
New London Bay	29-Oct-01	12:15	0.25	9.16	0.186	0.00	0.165
New London Bay	5-Nov-01	14:15	0.23	1.89	0.084	0.00	0.190

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
New London Bay	13-Nov-01	11:15	1.74	9.69	0.274	0.21	0.126
New London Bay	19-Nov-01	12:00	2.51	4.14	0.413	1.79	0.358
New London Bay	28-Nov-01	11:15	2.89	3.01	0.371	0.68	0.259
New London Bay	3-Dec-01	10:00	2.25	2.24	0.337	0.72	0.481
New London Bay	5-Sep-02		0.22	4.29	0.092	10.31	0.640
New London Bay	9-Sep-02		0.13	3.42	0.063	5.01	0.478
New London Bay	17-Sep-02		0.75	2.93	0.142	0.55	0.261
New London Bay	23-Sep-02		0.14	2.00	0.162	0.50	0.279
New London Bay	1-Oct-02		0.48	1.70	0.099	0.56	0.260
New London Bay	9-Oct-02		0.30	2.88	0.216	0.00	0.297
New London Bay	16-Oct-02		0.31	1.25	0.076	0.00	0.317
New London Bay	21-Oct-02		0.96	0.51	1.307	0.13	0.309
New London Bay	28-Oct-02		2.39	3.34	0.197	2.76	0.433
New London Bay	4-Nov-02		3.58	2.79	0.182	2.41	0.319
New London Bay	12-Nov-02		2.95	1.90	0.152	1.66	0.302
New London Bay	20-Nov-02		4.79	3.77	0.209	2.25	0.391
New London Bay	26-Nov-02		6.52	3.21	0.173	3.26	0.326
New London Bay	15-Sep-03		0.13	1.70	0.092	2.34	0.649
New London Bay	22-Sep-03		0.05	1.00	0.100	0.82	0.495
New London Bay	30-Sep-03		0.12	1.85	0.134	1.25	0.433
New London Bay	6-Oct-03		0.05	0.59	0.077	0.13	0.391
New London Bay	14-Oct-03		0.15	3.17	0.182	0.52	0.327
New London Bay	20-Oct-03		0.24	0.70	0.085	1.41	0.374
New London Bay	27-Oct-03		0.82	1.73	0.104	2.56	0.474
New London Bay	3-Nov-03		1.96	2.63	0.187	4.96	0.496
New London Bay	10-Nov-03		1.61	1.55	0.163	3.46	0.367
New London Bay	17-Nov-03		0.60	0.33	0.103	2.22	0.229
New London Bay	24-Nov-03		0.78	2.80	0.120	1.79	0.292
New London Bay	2-Dec-03		0.33	1.57	0.092	1.00	0.245
Rustico Bay	9-Oct-01	13:00	0.31	2.74	0.113	0.23	0.172
Rustico Bay	25-Oct-01	14:10	0.32	12.87	0.189	0.05	0.042
Rustico Bay	29-Oct-01	13:00	0.36	16.47	0.307	0.09	0.069
Rustico Bay	5-Nov-01	15:30	0.59	3.11	0.137	0.21	0.143
Rustico Bay	13-Nov-01	14:30	1.19	4.67	0.168	0.29	0.010
Rustico Bay	19-Nov-01	13:00	5.29	11.20	0.331	2.62	0.255
Rustico Bay	26-Nov-01	14:00	4.95	2.89	0.231	2.62	0.386
Rustico Bay	3-Dec-01	11:00	3.99	1.97	0.225	2.41	0.389
Rustico Bay	4-Sep-02		0.22	4.02	0.271	1.32	0.637
Rustico Bay	9-Sep-02		0.16	3.82	0.102	1.09	0.612
Rustico Bay	23-Sep-02		0.12	1.55	0.090	4.46	0.390
Rustico Bay	1-Oct-02		0.19	1.59	0.084	3.84	0.504
Rustico Bay	9-Oct-02		0.29	3.18	0.077	4.28	0.454
Rustico Bay	16-Oct-02		0.61	3.89	0.147	1.80	0.374
Rustico Bay	21-Oct-02		2.17	5.36	0.212	2.51	0.476
Rustico Bay	28-Oct-02		3.12	3.82	0.303	1.65	0.468

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
Rustico Bay	4-Nov-02		7.54	4.56	0.227	2.89	0.424
Rustico Bay	12-Nov-02		12.34	5.70	0.248	3.70	0.435
Rustico Bay	20-Nov-02		15.20	20.31	0.401	5.33	0.542
Rustico Bay	26-Nov-02		22.59	6.35	0.349	7.79	0.292
Rustico Bay	15-Sep-03		0.06	0.60	0.025	1.10	0.488
Rustico Bay	22-Sep-03		0.08	1.89	0.049	1.33	0.817
Rustico Bay	30-Sep-03		0.21	3.17	0.123	1.70	0.652
Rustico Bay	6-Oct-03		0.18	3.07	0.128	0.72	0.844
Rustico Bay	14-Oct-03		0.47	3.50	0.117	1.33	0.456
Rustico Bay	20-Oct-03		0.45	2.99	0.109	1.70	0.351
Rustico Bay	27-Oct-03		2.34	4.48	0.186	3.81	0.341
Rustico Bay	3-Nov-03		2.40	5.91	0.225	5.69	0.475
Rustico Bay	10-Nov-03		3.24	5.06	0.291	3.62	0.196
Rustico Bay	24-Nov-03		5.06	4.78	0.348	3.10	0.250
Rustico Bay	2-Dec-03		4.12	5.66	0.343	2.38	0.249
Savage Harbour	1-Oct-01		0.23	92.17	0.150	0.83	0.393
Savage Harbour	22-Oct-01		1.81	136.10	0.292	2.25	0.463
Savage Harbour	30-Oct-01		0.33	1.67	0.120	0.84	0.246
Savage Harbour	6-Nov-01		0.00	4.90	0.076	0.10	0.130
Savage Harbour	14-Nov-01		1.24	5.28	0.170	2.13	0.724
Savage Harbour	20-Nov-01		1.09	3.34	0.170	1.84	0.487
Savage Harbour	27-Nov-01		2.95	26.01	0.102	2.74	0.435
Savage Harbour	3-Dec-01		1.86	4.37	0.126	2.42	0.588
Savage Harbour	11-Dec-01		1.25	2.06	0.110	1.37	0.301
Savage Harbour	17-Dec-01		2.30	2.13	0.104	1.13	0.157
Savage Harbour	3-Sep-02		0.58	2.17	0.172	3.48	0.607
Savage Harbour	11-Sep-02		0.84	1.19	0.094	1.61	0.541
Savage Harbour	17-Sep-02		1.31	7.02	0.208	5.28	0.465
Savage Harbour	25-Sep-02		1.46	4.10	0.106	0.60	0.522
Savage Harbour	9-Oct-02		0.87	3.03	0.129	4.73	0.634
Savage Harbour	23-Oct-02		1.44	2.08	0.093	3.66	0.572
Savage Harbour	31-Oct-02		0.36	1.05	0.064	0.14	0.420
Savage Harbour	4-Nov-02		1.25	0.92	0.105	0.00	0.347
Savage Harbour	13-Nov-02		0.60	1.00	0.098	0.55	0.157
Savage Harbour	20-Nov-02		1.55	1.61	0.120	0.00	0.438
Savage Harbour	11-Sep-03		0.38	2.68	0.103	1.00	0.390
Savage Harbour	25-Sep-03		0.12	1.28	0.073	1.62	0.424
Savage Harbour	6-Oct-03		0.39	1.96	0.075	0.71	0.252
Savage Harbour	15-Oct-03		0.31	1.64	0.069	1.16	0.230
Savage Harbour	22-Oct-03		1.64	1.27	0.086	2.18	0.177
Savage Harbour	29-Oct-03		1.19	3.87	0.159	2.93	0.284
Savage Harbour	5-Nov-03		1.27	3.59	0.175	3.03	0.253
St. Marys Bay	4-Oct-01		0.00	1.22	0.064	0.69	0.414
St. Marys Bay	10-Oct-01		1.78	29.18	0.090	1.47	0.506
St. Marys Bay	23-Oct-01		0.24	1.03	0.064	1.44	0.208

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
St. Marys Bay	29-Oct-01		0.46	1.70	0.163	2.08	0.401
St. Marys Bay	5-Nov-01		0.20	16.99	0.093	0.08	0.323
St. Marys Bay	13-Nov-01		0.78	1.99	0.102	0.15	0.112
St. Marys Bay	19-Nov-01		0.93	3.48	0.096	0.00	0.133
St. Marys Bay	26-Nov-01		0.21	3.31	0.090	0.00	0.200
St. Marys Bay	3-Dec-01		0.69	1.86	0.109	0.00	0.340
St. Marys Bay	10-Dec-01		0.93	1.00	0.062	0.45	0.101
St. Marys Bay	17-Dec-01		0.94	1.24	0.080	0.33	0.256
St. Marys Bay	9-Sep-02		0.39	2.00	0.117	7.25	1.205
St. Marys Bay	16-Sep-02		0.40	1.98	0.094	5.32	1.081
St. Marys Bay	23-Sep-02		0.10	2.32	0.063	5.25	0.475
St. Marys Bay	8-Oct-02		0.29	2.86	0.064	6.38	0.718
St. Marys Bay	21-Oct-02		0.39	1.02	0.108	6.74	1.320
St. Marys Bay	6-Nov-02		2.54	1.93	0.246	2.75	0.306
St. Marys Bay	12-Nov-02		4.87	1.95	0.182	0.94	0.333
St. Marys Bay	18-Nov-02		0.57	1.21	0.078	1.27	0.517
St. Marys Bay	26-Nov-02		3.58	2.10	0.192	5.50	0.355
St. Marys Bay	15-Sep-03		0.10	0.86	0.062	0.35	0.301
St. Marys Bay	23-Sep-03		0.39	0.36	0.077	0.63	0.314
St. Marys Bay	1-Oct-03		0.09	0.76	0.063	0.80	0.319
St. Marys Bay	14-Oct-03		0.07	0.35	0.065	0.53	0.253
St. Marys Bay	20-Oct-03		0.13	0.44	0.059	0.19	0.220
St. Marys Bay	27-Oct-03		0.14	1.31	0.073	0.24	0.222
St. Marys Bay	3-Nov-03		0.07	1.09	0.054	2.30	0.115
St. Peters Bay	1-Oct-01		0.00	5.35	0.057	1.47	0.484
St. Peters Bay	22-Oct-01		1.64	2.49	1.464	0.91	0.442
St. Peters Bay	30-Oct-01		1.15	5.09	0.266	1.21	0.299
St. Peters Bay	8-Nov-01		0.58	0.80	0.133	0.49	0.288
St. Peters Bay	13-Nov-01		0.90	4.47	0.100	1.11	0.228
St. Peters Bay	20-Nov-01		3.91	2.94	0.167	4.85	0.794
St. Peters Bay	27-Nov-01		6.42	8.98	0.165	5.84	0.350
St. Peters Bay	3-Dec-01		2.96	1.19	0.168	3.64	0.325
St. Peters Bay	11-Dec-01		3.34	1.06	0.155	4.15	0.341
St. Peters Bay	17-Dec-01		2.58	2.01	0.111	1.39	0.177
St. Peters Bay	3-Sep-02		0.60	1.69	0.125	1.75	0.549
St. Peters Bay	11-Sep-02		0.37	2.36	0.084	4.16	0.582
St. Peters Bay	17-Sep-02		0.92	5.26	0.150	3.38	0.424
St. Peters Bay	25-Sep-02		1.07	5.51	0.203	4.19	0.338
St. Peters Bay	9-Oct-02		1.07	2.09	0.118	0.09	0.214
St. Peters Bay	16-Oct-02		1.93	4.67	0.197	6.13	0.510
St. Peters Bay	23-Oct-02		0.50	1.52	0.091	2.05	0.450
St. Peters Bay	31-Oct-02		2.65	1.38	0.124	3.96	0.406
St. Peters Bay	4-Nov-02		2.09	3.25	0.253	0.98	0.875
St. Peters Bay	13-Nov-02		1.93	1.47	0.174	2.40	0.132
St. Peters Bay	20-Nov-02		0.86	1.24	0.109	0.06	0.448

Inlet	Date	Time	NO_3	NH_3	NO_2	Si	PO_4
St. Peters Bay	11-Sep-03		0.28	1.94	0.083	1.30	0.578
St. Peters Bay	16-Sep-03		1.06	1.00	0.072	1.25	0.331
St. Peters Bay	25-Sep-03		0.74	0.55	0.073	1.84	0.269
St. Peters Bay	6-Oct-03		0.70	3.26	0.149	1.07	0.370
St. Peters Bay	15-Oct-03		0.27	1.05	0.069	0.68	0.307
St. Peters Bay	22-Oct-03		1.45	2.18	0.118	2.69	0.372
St. Peters Bay	29-Oct-03		3.28	4.47	0.209	6.88	0.446
St. Peters Bay	5-Nov-03		4.62	6.01	0.328	8.94	0.476
Tracadie Bay	1-Oct-01		0.05	1.32	0.091	0.92	0.365
Tracadie Bay	25-Oct-01		0.35	2.47	0.098	1.58	0.236
Tracadie Bay	30-Oct-01		0.36	7.40	0.170	0.24	0.060
Tracadie Bay	8-Nov-01		0.38	2.02	0.083	1.10	0.378
Tracadie Bay	14-Nov-01		0.99	73.09	0.147	0.85	0.095
Tracadie Bay	20-Nov-01		1.60	4.42	0.148	1.46	0.230
Tracadie Bay	27-Nov-01		2.15	3.15	0.209	1.73	0.167
Tracadie Bay	3-Dec-01		2.43	1.67	0.212	1.94	0.340
Tracadie Bay	11-Dec-01		2.69	1.57	0.268	2.21	0.207
Tracadie Bay	17-Dec-01		3.13	1.47	0.158	1.95	0.204
Tracadie Bay	3-Sep-02		2.44	2.44	0.321	1.59	0.603
Tracadie Bay	10-Sep-02		0.59	1.52	0.084	1.33	0.463
Tracadie Bay	17-Sep-02		7.51	6.13	0.268	4.95	0.576
Tracadie Bay	28-Sep-02		0.51	4.93	0.214	1.15	0.478
Tracadie Bay	9-Oct-02		0.18	3.94	0.070	0.72	0.359
Tracadie Bay	16-Oct-02		1.32	2.81	0.124	1.99	0.342
Tracadie Bay	23-Oct-02		0.36	1.15	0.044	0.74	0.248
Tracadie Bay	4-Nov-02		1.02	1.53	0.121	0.65	0.348
Tracadie Bay	13-Nov-02		7.29	1.82	0.277	5.58	0.320
Tracadie Bay	11-Sep-03		0.34	3.64	0.142	1.52	0.486
Tracadie Bay	25-Sep-03		0.63	0.68	0.077	1.36	0.244
Tracadie Bay	30-Sep-03		0.75	0.81	0.144	3.64	0.257
Tracadie Bay	6-Oct-03		0.45	5.81	0.263	1.25	0.262
Tracadie Bay	22-Oct-03		0.62	3.20	0.105	2.37	0.262
Tracadie Bay	29-Oct-03		1.53	4.66	0.187	4.80	0.288
Tracadie Bay	5-Nov-03		2.17	5.04	0.216	5.56	0.357

Appendix C. Nutrient statistics, by inlet.

Appendix C1. Nitrate statistics, by inlet.

Site	Mean	Mean - sd	Mean + sd	Number	Min	Max
Boughton River	0.76	0.23	2.13	29	0.11	7.58
Brudenell River	0.75	0.15	2.77	30	0.00	14.07
Cardigan River	0.45	0.09	1.51	31	0.00	9.80
Covehead Bay	1.00	0.27	3.18	21	0.00	6.25
Darnley Basin	0.70	0.18	2.17	34	0.08	6.05
Lennox Channel	0.16	0.03	0.44	33	0.03	4.41
March Water	0.16	0.05	0.34	10	0.04	0.60
Murray River	0.58	0.16	1.73	29	0.03	4.15
New London Bay	0.58	0.11	2.08	34	0.00	6.52
Rustico Bay	1.15	0.19	5.26	31	0.06	22.59
Savage Harbour	0.81	0.31	1.92	27	0.00	2.95
St. Marys Bay	0.42	0.09	1.30	27	0.00	4.87
St. Peters Bay	1.20	0.43	3.10	29	0.00	6.42
Tracadie Bay	0.98	0.31	2.74	26	0.05	7.51
All Inlets	0.64	0.14	2.15	391	0.00	22.59

Appendix C2. Ammonia statistics, by inlet.

Site	Mean	Mean - sd	Mean + sd	Number	Min	Max
Boughton River	2.06	0.75	5.67	29	0.46	56.20
Brudenell River	2.24	0.79	6.37	30	0.42	52.62
Cardigan River	2.55	0.58	11.22	31	0.48	100.30
Covehead Bay	1.96	0.85	4.51	21	0.52	14.13
Darnley Basin	3.05	1.77	5.27	34	1.15	22.88
Lennox Channel	0.96	0.42	2.18	33	0.14	3.77
March Water	1.44	0.48	4.33	10	0.32	17.08
Murray River	1.90	0.75	4.84	29	0.44	31.68
New London Bay	2.12	0.94	4.78	34	0.33	12.79
Rustico Bay	4.06	2.00	8.21	31	0.60	20.31
Savage Harbour	3.33	0.96	11.53	27	0.92	136.10
St. Marys Bay	1.65	0.63	4.32	27	0.35	29.18
St. Peters Bay	2.34	1.15	4.73	29	0.55	8.98
Tracadie Bay	2.85	1.14	7.13	26	0.68	73.09
All Inlets	2.23	0.82	6.09	391	0.14	136.10

Appendix C3. Nitrite statistics, by inlet.

Site	Mean	Mean - sd	Mean + sd	Number	Min	Max
Boughton River	0.122	0.075	0.199	29	0.065	0.544
Brudenell River	0.106	0.067	0.167	30	0.051	0.317
Cardigan River	0.086	0.052	0.143	31	0.029	0.246
Covehead Bay	0.121	0.073	0.202	21	0.048	0.326
Darnley Basin	0.155	0.096	0.251	34	0.062	0.415
Lennox Channel	0.086	0.054	0.136	33	0.046	0.299
March Water	0.096	0.056	0.164	10	0.047	0.246
Murray River	0.099	0.063	0.156	29	0.050	0.243
New London Bay	0.147	0.077	0.277	34	0.062	1.307
Rustico Bay	0.168	0.089	0.320	31	0.025	0.401
Savage Harbour	0.116	0.080	0.167	27	0.064	0.292
St. Marys Bay	0.088	0.059	0.132	27	0.054	0.246
St. Peters Bay	0.143	0.077	0.266	29	0.057	1.464
Tracadie Bay	0.146	0.088	0.241	26	0.044	0.321
All Inlets	0.118	0.068	0.206	391	0.025	1.464

Appendix C4. TIN (NO_3 + NO_2 +NH_3) statistics, by inlet.

Site	Mean	Mean - sd	Mean + sd	Number	Min	Max
Boughton River	3.37	1.34	8.48	29	1.03	56.81
Brudenell River	3.42	1.16	10.07	30	0.50	53.40
Cardigan River	3.58	0.90	14.22	31	0.48	102.62
Covehead Bay	3.23	1.36	7.69	21	0.87	15.09
Darnley Basin	4.02	2.16	7.48	34	1.29	23.59
Lennox Channel	1.17	0.52	2.65	33	0.17	6.70
March Water	1.60	0.54	4.75	10	0.36	17.33
Murray River	2.77	1.15	6.65	29	0.58	32.15
New London Bay	3.04	1.35	6.86	34	0.58	13.07
Rustico bay	5.93	2.48	14.14	31	0.66	35.51
Savage Harbour	4.59	1.50	14.06	27	1.40	137.91
St. Marys Bay	2.26	0.87	5.87	27	0.42	30.96
St. Peters Bay	3.90	2.12	7.19	29	1.30	15.40
Tracadie Bay	4.40	1.92	10.10	26	1.32	74.08
All Inlets	3.22	1.19	8.73	391	0.17	137.91

Appendix C5. Silicate statistics, by inlet.

Site	Mean	Mean - sd	Mean + sd	Number	Min	Max
Boughton River	1.36	0.46	3.66	29	0.00	4.16
Brudenell River	1.06	0.20	4.30	30	0.00	8.49
Cardigan River	1.77	0.44	6.36	31	0.00	9.89
Covehead Bay	1.11	0.28	3.72	21	0.00	5.97
Darnley Basin	1.09	0.41	2.68	34	0.00	4.74
Lennox Channel	0.50	0.10	1.75	33	0.00	8.03
March Water	0.52	0.21	1.11	10	0.10	1.47
Murray River	2.49	0.84	7.07	29	0.00	9.61
New London Bay	0.80	0.15	3.18	34	0.00	10.31
Rustico Bay	1.67	0.54	4.78	31	0.05	7.79
Savage Harbour	1.17	0.33	3.65	27	0.00	5.28
St. Marys Bay	0.87	0.15	3.68	27	0.00	7.25
St. Peters Bay	1.86	0.64	5.11	29	0.06	8.94
Tracadie Bay	1.62	0.78	3.28	26	0.24	5.58
All Inlets	1.20	0.32	4.00	391	0.00	10.31

Appendix C6. Phosphate statistics, by inlet.

Site	Mean	Mean - sd	Mean + sd	Number	Min	Max
Boughton River	0.423	0.141	0.704	29	0.170	1.476
Brudenell River	0.416	0.230	0.602	30	0.172	0.883
Cardigan River	0.533	0.242	0.825	31	0.204	1.509
Covehead Bay	0.412	0.117	0.707	21	0.189	1.305
Darnley Basin	0.558	0.354	0.763	34	0.161	1.072
Lennox Channel	0.442	0.221	0.663	33	0.157	1.265
March Water	1.087	0.712	1.461	10	0.385	1.627
Murray River	0.550	0.315	0.785	29	0.185	1.275
New London Bay	0.342	0.217	0.466	34	0.126	0.649
Rustico Bay	0.393	0.191	0.596	31	0.010	0.844
Savage Harbour	0.394	0.232	0.556	27	0.130	0.724
St. Marys Bay	0.409	0.090	0.728	27	0.101	1.320
St. Peters Bay	0.407	0.243	0.571	29	0.132	0.875
Tracadie Bay	0.314	0.183	0.446	26	0.060	0.603
All Inlets	0.450	0.193	0.706	391	0.010	1.627

Appendices D-F. Phytoplankton cell numbers (cells L^{-1}), in all Prince Edward Island inlets studied, 2001–2003.

Codes for *Pseudo-nitzschia* species were assigned based on cell shape, as observed by light microscopy (LM). Scanning electron microscopy (SEM) was later used to assign species identification, when possible (see Table 3, Materials and Methods section). The identification of *P. subpacifica* is tentative, because no SEM images were obtained. Although no SEM images were available for *P. americana*, its identification is based on its distinct morphology, as observed by LM. *P. pungens* and *P. multiseries* cannot be distinguished by LM. Codes in the Appendices are as follows:

Pseudo-nitzschia sp. #1 = *Pseudo-nitzschia delicatissima*
Pseudo-nitzschia sp. #2a = *Pseudo-nitzschia calliantha* (long cells)
Pseudo-nitzschia sp. #2b = *Pseudo-nitzschia calliantha* (short, "younger" cells)
Pseudo-nitzschia sp. #3 = *Pseudo-nitzschia pungens* or *P. multiseries*
Pseudo-nitzschia sp. #4 = *Pseudo-nitzschia seriata*
Pseudo-nitzschia sp. #5 = *Pseudo-nitzschia fraudulenta*
Pseudo-nitzschia sp. #6 = *Pseudo-nitzschia* cf. *subpacifica*

Notes:

1) The *Prorocentrum micans* indicated in Appendices D-F as "(Bérard)" is similar in shape to that described in Bérard *et al.* (1999), Plates 63a and 63b.
2) The other *Prorocentrum micans* is similar in shape to that described by Horner (2002; p. 112), and observed in the Bay of Fundy (M. LeGresley, personal communication, DFO St. Andrews, NB).
3) *Karenia mikimotoi* was identified by Dr. Gert Hansen (Biological Institute, Copenhagen, Denmark).

Appendix D1. Phytoplankton cell numbers (cells L^{-1}), in Cardigan River, 2001.

Species	26-Sep	4-Oct	10-Oct	24-Oct	31-Oct	5-Nov	13-Nov	19-Nov	26-Nov	3-Dec	10-Dec	17-Dec
Achnanthes spp.												40
Armoured dinoflagellate	1,445	1,156	578		2,890	340	2,320		1,120	666	480	
Cerataulina pelagica	289	578	289									
Chaetoceros contortus		4,624	137,564		5,780	17,640	5,280			2,131		
Chaetoceros danicus					289	400	320	1,156				40
Chaetoceros didymus	1,156	2,890	289					1,734				
Chaetoceros ingolfianus		2,890										
Chaetoceros lorenzianus	1,156	2,890	2,890									
Chaetoceros socialis		17,340	578		1,734							
Chaetoceros spp.	3,468	11,560	13,872		1,156	1,520	8,400	13,005	24,544	2,664	480	1,280
Chaetoceros teres		3,468	289	4,624								
Coscinodiscus spp.				1,734								
Cylindrotheca closterium	289	578		4,624	867	640			480		160	80
Cylindrotheca gracilis											480	80
Dactyliosolen fragilissimus		1,156	1,156	2,312	6,763	7,440	2,389	7,225	18,000	4,662	8,896	1,860
Detonula confervacea												160
Dictyocha fibula			578			80						
Dictyocha speculum					578	80	240		1,280	133		
Dinobryon spp.												40
Ebria tripartita		578	289			80	160	578	160			
Eutreptia / Eutreptiella	289	1,156				80						40
Flagellate									2,240	133		
Grammatophora marina								867				
Guinardia delicatula	289	1,734	578		289	800	1,280	3,179	3,312	1,518	4,800	1,040
Gyrodinium cf. *spirale*	5,202		289	578	1,156	80	80	578			480	
Gyrosigma balticum							240					
Gyrosigma tenuissimum						320	320			133		
Helicostomella spp.	289		578	2,890	5,202	640		289				
Heterocapsa triquetra	289				289		80					
Karenia mikimotoi	240,480	155,482	564,460	253,283	1,543,080	733,130	138,142	2,601	3,840			
Leptocylindrus danicus						1,040		2,312	640		1,120	476
Leptocylindrus mediterraneus						800	160					
Leptocylindrus minimus	1,156				2,312			4,046	18,096	9,324	36,736	10,608

Species	26-Sep	4-Oct	10-Oct	24-Oct	31-Oct	5-Nov	13-Nov	19-Nov	26-Nov	3-Dec	10-Dec	17-Dec
Licmophora abbreviata							160			266	160	120
Melosira spp.										533		40
Mesodinium rubrum									1,760	266		160
Protoperidinium bipes								578				
Navicula spp.								289				40
Odontella aurita										133		
Paralia marina					1,445		2,000	1,734	1,280		1,280	880
Pennate diatom				1,156	578	320	160	578	160		160	120
Phalacroma sp.	289											
Pleurosigma / Gyrosigma					867	160	720	289		400		
Pleurosigma angulatum				578	578	720		289		133	160	40
Prorocentrum micans	867		1,734	1,734	1,156	320	160					
Prorocentrum minimum	1,445						80				160	
Prorocentrum spp.									960	133		
Protoperidinium cf. *conicum*						400	640					
Protoperidinium spp.			289						480	266		
Pseudo-nitzschia sp. #1					3,468	257,180	33,400	2,189,370	237,140	356,267	223,363	88,510
Pseudo-nitzschia sp. #2a	3,179		578	45,315	70,516	350,700	1,703,400	904,583	1,683,360	2,154,300	1,862,050	804,940
Pseudo-nitzschia sp. #2b									2,288	3,903	3,952	4,760
Pseudo-nitzschia sp. #3	31,501	327,320	551,100	123,692	71,383	16,272	2,360	5,780		3,343	1,920	1,000
Pseudo-nitzschia sp. #4												
Pseudo-nitzschia sp. #5							80	578	1,440			200
Rhizosolenia hebetata var. *hebetata*					289		80	5,491				
Rhizosolenia hebetata var. *semispina*	289	578	578	13,294	6,936	3,280	3,440	1,734	3,040	799	480	80
Rhizosolenia imbricata	289	578		578		2,640	2,560	867	5,120	1,732	960	200
Rhizosolenia pungens				5,780	4,335	8,640	2,400	289		133		80
Rhizosolenia setigera							400				320	
Skeletonema costatum	3,256,500	550,834	923,434	36,992	7,537	27,200	60,344	8,381	17,152	1,332	6,352	1,400
Striatella unipunctata				578		80	80	289				
Thalassionema nitzschioides												280
Thalassiosira nordenskioeldii									160			2,800
Thalassiosira spp.	2,890											
Unarmoured dinoflagellate									640	533		120

Appendix D2. Phytoplankton cell numbers (cells L^{-1}), in Tracadie Bay, 2001.

Species	1-Oct	25-Oct	30-Oct	8-Nov	14-Nov	20-Nov	27-Nov	3-Dec	11-Dec	17-Dec
Amphidinium cf. *sphenoides*		400								
Armoured dinoflagellate	40	80			40				80	
Ceratium longipes		80								
Chaetoceros contortus	1,050	320	640							
Chaetoceros danicus			40					40		
Chaetoceros socialis	520					960				
Chaetoceros spp.	4,224	9,684	39,280	32,513	1,872	640	9,600	12,960	2,760	5,760
Cylindrotheca closterium	120	200	40	578	80	120	160	80	640	400
Cylindrotheca gracilis							40		80	
Dactyliosolen fragilissimus	1,980	1,976	1,260		80		80			
Detonula confervacea							160	280	440	
Dictyocha fibula		40								
Dinobryon spp.								40		
Eutreptia / Eutreptiella	80	240	240			40	40	880	360	240
Guinardia delicatula	520	400	400	2,312	160	40				
Gyrodinium cf. *spirale*		40								
Gyrosigma fasciola			40			40				80
Gyrosigma littorale										80
Gyrosigma tenuissimum	20				120	80				
Karenia mikimotoi		2,720								
Leptocylindrus danicus	264									
Leptocylindrus minimus	140					160	160			3,760
Licmophora abbreviata	20	40			80	40	280	960	360	2,000
Melosira spp.									960	
Mesodinium rubrum		40	40				80			
Paralia marina				4,624	360					
Pennate diatom	20	40			120	240	320	240	1,600	400
Pleurosigma / Gyrosigma	20		40			40				
Pleurosigma angulatum				578						
Prorocentrum micans	20									
Prorocentrum minimum			40						40	
Prorocentrum spp.										
Protoperidinium cf. *conicum*										

Species	1-Oct	25-Oct	30-Oct	8-Nov	14-Nov	20-Nov	27-Nov	3-Dec	11-Dec	17-Dec
Protoperidinium spp.	20									
Pseudo-nitzschia sp. #1		4,224	2,300	8,670	960	520	760	400	200	80
Pseudo-nitzschia sp. #2a	100	12,300	10,192	80,920	9,984	15,640	9,360	16,960	880	21,680
Pseudo-nitzschia sp. #2b		1,288		2,312	396	650	160	320		80
Pseudo-nitzschia sp. #3	220	2,080	800				120			
Pseudo-nitzschia sp. #4										
Pseudo-nitzschia sp. #5						120				240
Rhabdonema spp.							40			
Rhizosolenia hebetata var.*hebetata*		120								
Rhizosolenia hebetata var. *semispina*	120	1,480	440	1,734	120	120	120	40		
Rhizosolenia imbricata						40				
Rhizosolenia sp. (fragment)		40		578						
Scrippsiella spp.	20									
Scrippsiella trochoidea					40					
Skeletonema costatum	674,680	380,902	726,546	387,260	350,846	43,200	29,400	75,400	40,440	21,840
Striatella unipunctata		40	40					40		
Thalassiosira spp.		280						80		

Appendix D3. Phytoplankton cell numbers (cells L^{-1}), in New London Bay, 2001.

Species	3-Oct	9-Oct	19-Oct	25-Oct	29-Oct	5-Nov	15-Nov	19-Nov	28-Nov	3-Dec
Armoured dinoflagellate		200	440	320	320	480	80	80		
Chaetoceros contortus	320	320	320	800	520					
Chaetoceros debilis									400	
Chaetoceros lorenzianus	40		160						120	
Chaetoceros spp.	4,176	1,500	2,773	2,940	960	720			39,840	11,160
Cylindrotheca closterium					160	240			40	100
Cylindrotheca gracilis						40	20			100
Dactyliosolen fragilissimus	832	520	1,276		920	800	400	200	1,232	200
Detonula confervacea									1,040	
Dictyocha fibula			40	80						
Dictyocha speculum							20			
Dinobryon spp.					360	120	20			
Dinophysis acuminata		120	280		40	680				
Gonyaulax spinifera				40						
Guinardia delicatula	520		960	800	160		200		1,364	
Gyrodinium cf. *spirale*	720	1,280	1,600	200	240	160	20			
Gyrosigma balticum		40								
Gyrosigma fasciola		80		120	40	40				100
Gyrosigma tenuissimum						80				
Karenia mikimotoi			240		40					
Leptocylindrus danicus						120				
Leptocylindrus minimus		400		720			600	440	14,040	7,400
Licmophora abbreviata						40	20		160	
Melosira spp.							20			
Mesodinium rubrum		1,280	960	680	3,040	440	160			
Protoperidinium bipes						80				
Paralia marina							80			
Pennate diatom									40	100
Phalacroma sp.	440	40								
Pleurosigma / Gyrosigma		40								
Pleurosigma angulatum		120				40	20			
Prorocentrum micans	1,040									
Prorocentrum minimum	80					320	20		120	

Species	3-Oct	9-Oct	19-Oct	25-Oct	29-Oct	5-Nov	15-Nov	19-Nov	28-Nov	3-Dec
Prorocentrum spp.			40							
Protoperidinium cf. *conicum*				40	120					
Protoperidinium spp.			80		160	80				
Pseudo-nitzschia sp. #1		16,955	83,500	407,480	597,860	793,250	267,200	110,976	35,070	98,260
Pseudo-nitzschia sp. #2a	1,176	44,312	534,400	564,460	624,580	534,400	459,250	205,778	282,230	525,980
Pseudo-nitzschia sp. #2b									320	800
Pseudo-nitzschia sp. #3	880	22,348	17,024	3,302	520	5,964	1,144	6,320	5,320	1,200
Pseudo-nitzschia sp. #4										
Pseudo-nitzschia sp. #5								880	400	500
Rhizosolenia hebetata var. *hebetata*		80	80			80	20			
Rhizosolenia hebetata var. *semispina*	80	240	680	440	360	320	640	240	160	
Rhizosolenia imbricata	40			40		40	20	40		100
Rhizosolenia pungens					40					
Scrippsiella spp.		200	600			160				
Scrippsiella trochoidea		80	1,240	160			20			
Skeletonema costatum	116,256	885,100	54,629	5,645	6,072	171,046	3,402	9,768	454,886	780,300
Striatella unipunctata	480									
Thalassiosira spp.		1,560	9,504	640			60		160	200
Unarmoured dinoflagellate	1,080		80			40				

Appendix D4. Phytoplankton cell numbers (cells L^{-1}), in Lennox Channel (Malpeque Bay), 2001.

Species	11-Oct	19-Oct	23-Oct	1-Nov	5-Nov	14-Nov	21-Nov	26-Nov	4-Dec	10-Dec
Actinoptychus senarius								80		
Amphidinium cf. *sphenoides*	40		20							
Armoured dinoflagellate	200					80				
Ceratium fusus						80				
Chaetoceros contortus	2,000		280							
Chaetoceros danicus							40			
Chaetoceros lorenzianus	500									
Chaetoceros spp.	1,200	40				80	80	960	2,312	880
Cylindrotheca closterium	40	40			80	80			1,156	
Cylindrotheca gracilis		240								
Dactyliosolen fragilissimus	3,120	14,620	4,828	860	1,904	21,840	8,424	31,320	21,386	880
Dictyocha fibula	40		40							
Dinobryon spp.		200			120			240		
Dinophysis acuminata	160				80	80	40	80		
Eutreptia / Eutreptiella			20	60	40	160				
Flagellate									2,312	40
Guinardia delicatula	1,240	1,440	770	340	200	2,992	1,656	9,744	2,023	1,056
Gyrodinium cf. *spirale*										40
Gyrosigma balticum										
Gyrosigma fasciola	120		20	20	160				578	40
Gyrosigma tenuissimum	40		60	20	40	80				
Heterocapsa triquetra		120	100							
Karenia mikimotoi		40		60						
Leptocylindrus danicus		320	120	40						
Leptocylindrus minimus	160	2,040	380	2,680	2,960	17,280	11,213	134,640	248,135	309,808
Licmophora abbreviata				20			40	160	1,156	40
Mesodinium rubrum				240	240	80	40	1,040		
Protoperidinium bipes			80	20						
Paralia marina		320	80	80	400	800				
Pennate diatom	200	40	60	60	160	160			289	
Phalacroma sp.			20	40						
Pleurosigma / Gyrosigma		40								
Polykrikos cf. *kofoidii*	40									

Species	11-Oct	19-Oct	23-Oct	1-Nov	5-Nov	14-Nov	21-Nov	26-Nov	4-Dec	10-Dec
Prorocentrum micans	160	80								
Protoperidinium spp.	40		40		40					
Pseudo-nitzschia sp. #1	1,037,070	514,360	357,380	460,920	144,500	150,300	64,158	185,370	35,836	9,248
Pseudo-nitzschia sp. #2a	233,800	165,330	325,650	584,500	191,318	410,820	169,932	332,330	121,380	82,654
Pseudo-nitzschia sp. #2b									20230	19074
Pseudo-nitzschia sp. #3	16,925	4,300	3,633	70,140	10,200	880	1,600	7,320	289	640
Pseudo-nitzschia sp. #4	40									880
Pseudo-nitzschia sp. #5	160		140			1,120	840	3,464		480
Rhizosolenia hebetata var. *hebetata*			20				60			
Rhizosolenia hebetata var. *semispina*	160	480	820	1,280	320	4,480	200	240	289	
Rhizosolenia imbricata	200	80	40	40	80	160	40	80		
Rhizosolenia pungens			40	40						
Rhizosolenia spp.	80	80	100			160				
Scrippsiella spp.				20						
Scrippsiella trochoidea		40		40						
Skeletonema costatum	64,055	30,260	29,280	1,000	4,032	79,920	35,478	6,400		
Thalassiosira spp.	160									
Unarmoured dinoflagellate	160									80

Appendix D5. Phytoplankton cell numbers (cells L^{-1}), in March Water (Malpeque Bay), 2001.

Species	5-Nov	14-Nov
Armoured dinoflagellate	40	
Chaetoceros spp.	200	
Cylindrotheca closterium	100	
Dactyliosolen fragilissimus	1,450	1,080
Dinobryon spp.	80	
Eutreptia / Eutreptiella	40	
Guinardia delicatula	40	1,120
Gyrosigma fasciola	40	
Gyrosigma tenuissimum	20	
Leptocylindrus minimus	1,120	6,800
Pennate diatom		40
Pleurosigma / Gyrosigma	80	
Pseudo-nitzschia sp. #1	59,534	80,342
Pseudo-nitzschia sp. #2a	26,299	114,444
Pseudo-nitzschia sp. #2b	440	
Pseudo-nitzschia sp. #3	40	880
Pseudo-nitzschia sp. #4		
Pseudo-nitzschia sp. #5		80
Rhizosolenia hebetata var. *semispina*	220	1,280
Rhizosolenia imbricata		40
Scrippsiella trochoidea	20	
Skeletonema costatum	8,580	15,264

Appendix D6. Phytoplankton cell numbers (cells L^{-1}), in other inlets, 2001; 1= present; 2=common.

Location	Boughton River	Brudenell River	Covehead Bay	Darnley Basin	Murray River	Rustico Bay	Savage Harbour	St. Marys Bay	St. Peters Bay
Species	**19-Nov**	**29-Oct**	**15-Nov**	**26-Nov**	**19-Nov**	**26-Nov**	**20-Nov**	**5-Nov**	**20-Nov**
Chaetoceros lorenzianus		1							
Chaetoceros spp.			1					1	1
Cylindrotheca closterium		1					1	1	
Cylindrotheca gracilis				1					
Dactyliosolen fragilissimus	1	1	1	1				1	
Eutreptia / Eutreptiella								1	1
Guinardia delicatula		1		1					
Gyrosigma fasciola				1					
Leptocylindrus danicus								1	
Leptocylindrus minimus	1	1		1					
Licmophora abbreviata					1	1	1		1
Mesodinium rubrum	1								1
Odontella aurita							1		
Pennate diatom		1		1	1		1		
Pleurosigma angulatum					1				
Pseudo-nitzschia sp. #1	46,240	14,450	15,895	4,600	20,230		17,340	438,375	1
Pseudo-nitzschia sp. #2a	1,800,470	563,550	39,015	37,200	375,700	17,340	119,935	1,169,000	121,380
Pseudo-nitzschia sp. #2b	26,010	1	8,670	5,200	11,560	5,780	13,005	1	18,785
Pseudo-nitzschia sp. #3	52,020	54,910		1			1		1
Pseudo-nitzschia sp. #4									
Pseudo-nitzschia sp. #5							1		
Rhizosolenia hebetata var. *semispina*	1	1	1					1	
Rhizosolenia imbricata		1							
Rhizosolenia pungens		1							
Skeletonema costatum		2	2	2	1				
Striatella unipunctata							1		

Appendix E1. Phytoplankton cell numbers (cells L^{-1}), in Cardigan River, 2002.

Species	4-Sep	9-Sep	16-Sep	23-Sep	8-Oct	23-Oct	28-Oct	6-Nov	12-Nov	18-Nov
Alexandrium sp.		160								
Amphidinium sphenoides							578			
Armoured dinoflagellate	867	3,360	240	1,280	289	578	1,734			1,156
Centrale diatom					289	578				
Cerataulina pelagica					21,675	420,283	83,810	42,194	69,938	1,156
Ceratium fusus	867	2,080	160							
Chaetoceros contortus	22,629	11,936	11,232	151,152		6,936				
Chaetoceros danicus		320		1,280		578	578			
Chaetoceros debilis				3,440		2,312				
Chaetoceros decipiens							2,312			
Chaetoceros didymus			320	960		2,312				
Chaetoceros didymus var. *protuberans*			80	2,240	13,005	1,156				
Chaetoceros lorenzianus	7,370	4,960			6,647					
Chaetoceros similis						8,670	2,312	2,312	578	
Chaetoceros socialis	21,054	13,056	960		1,734	2,890		1,156		
Chaetoceros sp. A "filiform"		640	640	640	7,225	7,514	35,692		8,092	1,541
Chaetoceros spp.	6,503	4,416	5,840	23,520	2,312	3,468	10,404		1,156	5,009
Chaetoceros teres			320		1,156					
Chrosochromulina parkeae				160					289	
Corethron criophilum						1,156				
Coscinodiscus spp.	145	320								
Cyclotella spp.					14,450	14,566				
Cylindrotheca closterium	4,191	8,160	3,360	11,040	10,982	12,138	5,780		1,445	1,156
Dactyliosolen fragilissimus			640		293,913		44,506	36,067	9,248	7,321
Detonula confervacea										
Dictyocha fibula										
Dictyocha speculum						3,468	2,890			
Dinobryon spp.			320							
Dinophysis acuminata					289					
Dinophysis norvegica	145									
Ebria tripartita					2,890		1,156			
Eutreptia / Eutreptiella	1,156	1,280	320		2,601					

Species	4-Sep	9-Sep	16-Sep	23-Sep	8-Oct	23-Oct	28-Oct	6-Nov	12-Nov	18-Nov
Guinardia delicatula			1,688	1,280	158,950	5,202	16,068	16,473	3,237	11,020
Guinardia flaccida			80	5,824	578					
Gyrodinium cf. *spirale*	145			2,720						
Gyrodinium spp.	289		5,280		289					1,156
Gyrosigma balticum			80							
Gyrosigma littorale	1,156				1,734			578		
Karenia mikimotoi				480						
Leptocylindrus minimus					48,552	6,936	4,624	26,588		1,541
Licmophora abbreviata		160						578		385
Merismopedia sp.					578					
Mesodinium rubrum		320	480	320	5,202	1,734	578		578	1,541
Microcystis sp.					289					
Protoperidinium bipes								578	578	771
Navicula sp.			80				578		289	385
Paralia marina		640	1,120				2,312			2,312
Pennate diatom		800	720		2,890	2,312				
Phalacroma sp.	289		240	1,760		2,312	1,734			
Pleurosigma / Gyrosigma	289	4,960	1,600	960	578	578				
Pleurosigma angulatum	578	2,720	480	480	4,913		1,734			
Preperidinium meuneri	2,312	160			289					
Prorocentrum micans	2,312	480	320	1,120	1,445	578		578		
Prorocentrum minimum	37,570	6,400	1,200	2,720	7,803	6,936	6,358	3,468	1,445	771
Prorocentrum spp.									289	
Protoperidinium punctulatum/subinerme				320						
Protoperidinium spp.	289	320					2,312	1,156	578	1,927
Pseudo-nitzschia sp. #1				960	6,936	2,312				
Pseudo-nitzschia sp. #2a		320	400	640	10,809	88,434	2,187,700	2,254,500	2,404,800	5,328,579
Pseudo-nitzschia sp. #2b										
Pseudo-nitzschia sp. #3	37,888	11,146	9,840	5,104	56,991	2,312	8,670		4,913	
Pseudo-nitzschia sp. #4										
Pseudo-nitzschia sp. #5										
Rhizosolenia hebetata var. *hebetata*		160	3,600	4,480						385
Rhizosolenia hebetata var. *semispina*		320	1,360	7,520	2,601	1,156	1,156	578		

Species	4-Sep	9-Sep	16-Sep	23-Sep	8-Oct	23-Oct	28-Oct	6-Nov	12-Nov	18-Nov
Rhizosolenia imbricata		160	640	960	1,734	1,156	1,156	578	1,156	
Rhizosolenia pungens					867			1,156		
Rhizosolenia spp.					867			578		
Scrippsiella trochoidea							578			385
Skeletonema costatum	3,044,967	5,135,250	7,757,150	2,893,275	327,079	1,332,660	1,281,725	399,976	669,670	468,987
Thalassionema nitzschioides			800		36,356	13,872	13,178			
Thalassiosira "tiny" sp.							1,156			
Thalassiosira auguste-lineata	289									
Thalassiosira spp.	1,084	960	480	2,400	2,312	4,624	1,734		1,156	1,541
Unarmoured dinoflagellate		320	480	480			2,312	1,156	1,156	1,156

Appendix E2. Phytoplankton cell numbers (cells L^{-1}), in Tracadie Bay, 2002.

Species	3-Sep	10-Sep	17-Sep	25-Sep	9-Oct	16-Oct	23-Oct	13-Nov
Armoured dinoflagellate			20	120	160	193		80
Centrale diatom				40				
Cerataulina pelagica	212	660	420	17,600	5,440			
Chaetoceros contortus	88,688	3,680	600	10,168	27,160	19,786		
Chaetoceros debilis		160			400			
Chaetoceros didymus var. *protuberans*		20						
Chaetoceros lorenzianus	6,206	17,542	940	1,680	80			
Chaetoceros similis							240	
Chaetoceros socialis				5,572	16,240	5,433		
Chaetoceros sp. A "filiform"				560	880	5,972	160	1,720
Chaetoceros spp.	9,180	760	1,032	8,364	13,824	20,961	1,080	
Chaetoceros subtilis				160				
Chaetoceros teres		1,296		240				
Cylindrotheca closterium	60	80	320	280	400	193	120	160
Dactyliosolen fragilissimus	260	2,088	80	1,520	240		200	200
Eutintinnus sp.	20							
Eutreptia / Eutreptiella			20	1,480	480	385	760	920
Gonyaulax spp.	20							
Guinardia delicatula		80	976	4,320	6,600	4,624	1,360	40
Gyrodinium cf. *spirale*					80	193		80
Gyrosigma fasciola						193		
Leptocylindrus danicus	572	140	60	360				
Leptocylindrus minimus						193	80	
Licmophora abbreviata			40	40	480	385	40	40
Mesodinium rubrum	40	60	60	360	560		320	80
Paralia marina			120					
Pennate diatom	100		20			193	80	200
Pleurosigma / Gyrosigma	20	40		80				
Pleurosigma angulatum		20						
Proboscia alata							40	
Prorocentrum micans	20							
Prorocentrum minimum	100	420	520	640	5,120	1,156	3,880	2,440

Species	3-Sep	10-Sep	17-Sep	25-Sep	9-Oct	16-Oct	23-Oct	13-Nov
Prorocentrum spp.								40
Protoperidinium spp.					160			
Pseudo-nitzschia sp. #1		20	80					
Pseudo-nitzschia sp. #2a			80	520	49,600	161,256	98,838	121,958
Pseudo-nitzschia sp. #2b								
Pseudo-nitzschia sp. #3		100		5,148	320		120	
Pseudo-nitzschia sp. #4								
Pseudo-nitzschia sp. #5								
Rhizosolenia hebetata var. *hebetata*		60						
Rhizosolenia hebetata var. *semispina*		20	60	440		193		
Rhizosolenia imbricata	40	120	20	80	80			
Rhizosolenia pungens	40		40	800				
Skeletonema costatum	460	16,936	6,816	62,400	249,280	587,228	4,664	7,440
Thalassiosira spp.				80	1,440	385	280	
Unarmoured dinoflagellate						193		

Appendix E3. Phytoplankton cell numbers (cells L^{-1}), in New London Bay, 2002.

Species	4-Sep	9-Sep	17-Sep	23-Sep	1-Oct	9-Oct	16-Oct	21-Oct	28-Oct	4-Nov	12-Nov	20-Nov	26-Nov
Armoured dinoflagellate	160	2,601		10,560	1,280	520	320	1,760	160	320			40
Asterionellopsis glacialis	1,920										3,255	200	280
Centrale diatom			578	2,304	15,200	840	80				125	40	
Cerataulina pelagica	23,040	65,545	41,327	138,029	4,880	960	320						
Chaetoceros contortus									80				
Chaetoceros danicus		4,046	4,046	12,384		160							
Chaetoceros debilis	480												
Chaetoceros diadema		1,734								320	501	160	
Chaetoceros didymus									240				
Chaetoceros laciniosus					480	1,360	320	400	400	5,360	9,515	3,972	640
Chaetoceros lorenzianus	960	1,156											
Chaetoceros similis		289											
Chaetoceros simplex	3,040	41,067	24,276	27,706		120				2,720			
Chaetoceros socialis	640	4,046		768	1,920	120						3,520	320
Chaetoceros sp. A "filiform"	2,400	1,156	8,670	43,776	11,600	4,620	1,760	1,600	1,200	1,800	3,506	400	240
Chaetoceros spp.	320		1,156	1,728									
Chaetoceros teres	4,000												
Cyclotella spp.	29,280	29,767	8,670	9,792	6,640	640	480	320	1,120	80	125	240	160
Cylindrotheca closterium									160				120
Cylindrotheca gracilis	21,280	6,069	1,734	8,448	8,800			80					
Dactyliosolen fragilissimus										80			
Dictyocha speculum						240	1,120		800	480			
Dinobryon spp.					240		80		80			320	
Dinophysis acuminata	160	289											40
Ebria tripartita	640	289		768	640	40		160	320		125		40
Eutreptia / Eutreptiella	160												
Grammatophora marina	3,456	5,202	1,734	17,280	9,248	2,000	3,120	2,800	1,040	2,720	376	280	280
Guinardia delicatula				3,648	1,120	320	400	880	320	800	125	240	40
Gyrodinium cf. *spirale*		289		192	320	400							
Gyrodinium spp.	160			192									
Gyrosigma balticum	160								80			80	
Gyrosigma fasciola							80						
Gyrosigma littorale													

Species	4-Sep	9-Sep	17-Sep	23-Sep	1-Oct	9-Oct	16-Oct	21-Oct	28-Oct	4-Nov	12-Nov	20-Nov	26-Nov
Heterocapsa triquetra							80	80	80	560			
Karenia mikimotoi		289		192		40				160			
Leptocylindrus danicus	640												
Leptocylindrus mediterraneus													
Leptocylindrus minimus	9,472	1,156		8,640	3,680	320	1,120	800	1,920	1,280	2,128	800	
Licmophora abbreviata	1,600						80		400	160	250	40	
Melosira monoliformis	640												
Melosira spp.					960								
Merismopedia sp.		289						80					
Mesodinium rubrum	1,280	2,890		1,536	3,840	280	1,040	2,160		1,280	1,002	160	120
Protoperidinium bipes								80					
Paralia marina										1,120		480	320
Pennate diatom	160	3,468	9,248	768					160	80	250	240	200
Phalacroma sp.					240			240	320	80	125		
Pleurosigma / Gyrosigma						80			160				
Pleurosigma angulatum	160											40	80
Preperidinium meuneri									80	80			
Prorocentrum micans					80								
Prorocentrum minimum	2,560	1,445	142,766	16,896			480	1,440	1,760	160	376	1,520	200
Prorocentrum spp.	320	578						160		80		40	
Protoperidinium conicum								960		160			
Protoperidinium spp.		289		192	240	240	240	800	400				
Pseudo-nitzschia sp. #1	320	578	2,312										
Pseudo-nitzschia sp. #2a	2,640	4,624	13,294	15,053	191,318	106,880	985,300	1,002,000	165,888	215,432	244,491	158,950	62,424
Pseudo-nitzschia sp. #2b													
Pseudo-nitzschia sp. #3	320	63,551	236,402	47,808	10,320	5,480	5,200	640	80			400	
Pseudo-nitzschia sp. #4				384									
Pseudo-nitzschia sp. #5													
Rhizosolenia hebetata var. *hebetata*			578	4,032	800								
Rhizosolenia hebetata var. *semispina*	2,560	867		1,536	720	40	80	80					
Rhizosolenia imbricata		578		2,112	800	280	160	80					
Rhizosolenia pungens		289											
Rhizosolenia sp. (fragment)	480	1,445		960	800	360							

Species	4-Sep	9-Sep	17-Sep	23-Sep	1-Oct	9-Oct	16-Oct	21-Oct	28-Oct	4-Nov	12-Nov	20-Nov	26-Nov
Scrippsiella spp.				960	80								
Scrippsiella trochoidea				192	160			80				40	
Skeletonema costatum	215,360	860,642	2,076,176	846,029	1,579,824	178,160	14,000	2,560	12,880	118,080	169,270	170,380	31,716
Striatella unipunctata	160												
Thalassionema nitzschioides	1,280	578										80	
Thalassiosira nordenskioeldii							160			1,920	1,502	4,320	
Thalassiosira spp.			1,156	9,600	1,200		240		240	160	1,002		1,440
Unarmoured dinoflagellate						40			80			160	

Appendix E4. Phytoplankton cell numbers (cells L^{-1}), in Lennox Channel (Malpeque Bay), 2002.

Species	3-Sep	9-Sep	17-Sep	26-Sep	1-Oct	9-Oct	16-Oct	21-Oct	28-Oct	4-Nov	12-Nov	20-Nov
Alexandrium pseudogonyaulax	520	2,508	80									
Alexandrium sp.				80								
Armoured dinoflagellate	920		5,920	1,040	2,160	440	280	720	360	200	80	80
Asterionellopsis glacialis				160								
Cerataulina pelagica	3,200	5,940	320	80	1,280	360	200	80		40		
Ceratium fusus					80		80			40		
Chaetoceros contortus	27,200	17,503	44,488	23,664								
Chaetoceros debilis	240	1,584	4,184	2,240	320							
Chaetoceros didymus		132	240	6,600	4,160							
Chaetoceros lauderi/teres	896		320	240								
Chaetoceros lorenzianus	40			720	240							
Chaetoceros socialis	900	1,320	960	1,440								
Chaetoceros sp. A "filiform"	1,440		960		480			800	9,520	3,456	36,120	29,784
Chaetoceros spp.	3,736	70,125	46,800	52,632	7,912	80	1,000		480	600	320	960
Cylindrotheca closterium	280	2,376	4,880	1,040	160		40	40	40	40	80	240
Cylindrotheca gracilis								40	40	40	80	80
Dactyliosolen fragilissimus	1,360	45,883	5,952				80		320	80	200	720
Dinobryon spp.					400							
Dinophysis acuminata					160	40			80	40	480	
Dinophysis rotundata	40											
Entomoneis spp.											40	
Eutreptia / Eutreptiella	80		240	560	80	40					80	
Gonyaulax spinifera	40			80								
Guinardia delicatula	80	2,112	2,496	1,536	1,600	200	1,536	1,360	920	1,440	3,456	1,456
Gyrodinium cf. *spirale*			1,360	6,560	1,520	400	120	120	40	40		80
Gyrodinium spp.		264	160	480		40						
Gyrosigma fasciola											40	80
Heterocapsa triquetra			80			40	40		160	80	40	
Karenia mikimotoi	160	132	80	1,040	1,120	240	200	240	40			
Leptocylindrus danicus		2,376										
Leptocylindrus minimus		2,640	1,200					440	2,656	2,840	26,544	3,224
Licmophora abbreviata		264						40			40	240
Merismopedia sp.	2,480	2,376	1,280									

Species	3-Sep	9-Sep	17-Sep	26-Sep	1-Oct	9-Oct	16-Oct	21-Oct	28-Oct	4-Nov	12-Nov	20-Nov
Mesodinium rubrum	240		240		480	600	400	160		160	400	10,240
Microcystis sp.	1,400	4,620	3,760	80							40	
Protoperidinium bipes									40		40	
Paralia marina	200	528	560			160		160			240	
Pennate diatom	240	264	240	240	80	120	40		40	80	480	240
Phalacroma sp.				400	240				40			
Pleurosigma / Gyrosigma	40	264	160			40					40	80
Pleurosigma angulatum										40		
Polykrikos cf. *kofoidii*		264	240									
Preperidinium meuneri						40						
Prorocentrum micans	80			400	240		40					
Prorocentrum minimum	880	7,260	1,520	480	720	320	120	160	120	40	200	80
Prorocentrum spp.					240					40	120	
Protoperidinium cf. *conicum*						40						
Protoperidinium punctulatum/subinerme			240	80	160							
Protoperidinium spp.		132	480	880	480	80	160	240	80			
Pseudo-nitzschia sp. #1	40				160							
Pseudo-nitzschia sp. #2a		660	6,208	139,876	1,269,200	1,118,900	964,425	968,600	1,152,300	705,575	701,400	382,636
Pseudo-nitzschia sp. #2b												
Pseudo-nitzschia sp. #3		792	2,648	34,376	23,400	1,000	1,360	1,480	640	480		
Pseudo-nitzschia sp. #4												
Pseudo-nitzschia sp. #5			320	400	480							
Pyrocystis lunata												80
Rhizosolenia hebetata var. *hebetata*			320	560	80		40					
Rhizosolenia hebetata var. *semispina*	520	1,980	3,680	560	80	40				40	80	
Rhizosolenia imbricata	40	132	400	160	1,520	720	360	40	80	40	40	
Rhizosolenia pungens						40						
Rhizosolenia spp.		132	160	880	800	320	40			40		
Scrippsiella spp.				240	320	40						
Scrippsiella trochoidea								40				
Skeletonema costatum	199,716	2,104,200	1,070,888	40,800	83,080	1,960	2,240	1,240	920	3,392	30,624	99,104
Striatella unipunctata		66,528										
Thalassionema nitzschioides	720	11,154	480									

Species	3-Sep	9-Sep	17-Sep	26-Sep	1-Oct	9-Oct	16-Oct	21-Oct	28-Oct	4-Nov	12-Nov	20-Nov
Thalassiosira spp.			1,440	2,320	1,280				280			
Unarmoured dinoflagellate				21,760		40	520		40		40	160

Appendix E5. Phytoplankton cell numbers (cells L^{-1}), in Murray River, 2002.

Species	9-Sep	23-Sep	21-Oct	5-Nov	18-Nov
Achnanthes sp.			80		
Armoured dinoflagellate	640				
Brachionus spp.	160				
Cerataulina pelagica			1,120		
Chaetoceros contortus		19,200			
Chaetoceros debilis	1,440	3,302			
Chaetoceros didymus var. *protuberans*	21,440	10,944	160		
Chaetoceros similis	320				
Chaetoceros socialis	1,600				
Chaetoceros spp.	3,456	9,485	400		
Corethron criophilum			80		
Cylindrotheca closterium	27,200	17,088	320	80	320
Cylindrotheca gracilis				80	
Dactyliosolen fragilissimus	12,800	960	4,928	1,440	
Detonula confervacea					
Ebria tripartita			160		
Eutreptia / Eutreptiella	1,120	3,072	400	240	
Guinardia delicatula	2,080	1,766	1,320	240	
Guinardia flaccida		768		80	
Gyrosigma littorale	160	384			
Gyrosigma tenuissimum			80		
Leptocylindrus danicus		384			
Leptocylindrus minimus	1,280		800		
Licmophora abbreviata		192	80	80	
Mesodinium rubrum	800	2,112	480		480

Species	9-Sep	23-Sep	21-Oct	5-Nov	18-Nov
Paralia marina		768	400		480
Pediastrum sp. (freshwater sp.)				80	
Pennate diatom	640		560		720
Pleurosigma / Gyrosigma		384	320	80	
Pleurosigma angulatum		192			
Prorocentrum micans	480				
Prorocentrum minimum	2,560	576	2,720	80	
Prorocentrum spp.		192			
Protoperidinium spp.		192	80		
Pseudo-nitzschia sp. #1					
Pseudo-nitzschia sp. #2a		1,152	184,384	462,829	470,384
Pseudo-nitzschia sp. #2b					
Pseudo-nitzschia sp. #3	29,280	24,480	400	2,800	720
Pseudo-nitzschia sp. #4					
Pseudo-nitzschia sp. #5					
Rhizosolenia hebetata var. *hebetata*		192			
Rhizosolenia hebetata var. *semispina*	320	1,920	80		
Rhizosolenia imbricata			160	400	
Rhizosolenia sp. (fragment)	320	768	160		
Scrippsiella trochoidea				80	
Skeletonema costatum	236,912	484,301	1,010,352	940,290	1,020,368
Striatella unipunctata			80		160
Thalassionema nitzschioides		2,112	2,160		
Thalassiosira spp.		192	400		320
Unarmoured dinoflagellate	320	192			

Appendix E6. Phytoplankton cell numbers (cells L^{-1}), in other inlets, 2002.

Location	Boughton River	Brudenell River	Covehead Bay	Darnley Basin	Murray River	Rustico Bay	Savage Harbour	St. Marys Bay	St. Peters Bay
Species	**6-Nov**	**6-Nov**	**4-Nov**	**21-Oct**	**5-Nov**	**27-Oct**	**4-Nov**	**6-Nov**	**4-Nov**
Achnanthes sp.									80
Actinoptychus senarius				20					
Armoured dinoflagellate	160	160	80	60			120	200	
Bacillaria paxillifer								1,200	
Brachionus spp.			480						
Cerataulina pelagica	320	12,576	960					1,920	80
Chaetoceros contortus			640						
Chaetoceros similis		480	320						
Chaetoceros socialis		640							
Chaetoceros sp. A "filiform"			6,912				720	79,920	
Chaetoceros spp.	960		3,816	120		960		3,800	480
Cylindrotheca closterium	80		80	60	80	80	40	200	
Cylindrotheca gracilis			80		80				
Dactyliosolen fragilissimus	2,160	26,448	640	260	1,440		80	2,800	240
Detonula confervacea									
Dictyocha speculum	80	160							
Dinobryon spp.							520		480
Dinophysis rotundata				40					
Ebria tripartita	160	320							
Eutreptia / Eutreptiella	80	320		20	240	1,200			240
Guinardia delicatula	1,840	11,808	4,096	780	240	880	1,520	3,000	4,560
Guinardia flaccida					80				
Gyrodinium cf. *spirale*						80	40		
Gyrosigma balticum				40					
Gyrosigma fasciola	80	160		380		160			
Gyrosigma littorale		160		20					
Gyrosigma tenuissimum	240						40		
Leptocylindrus minimus	640	10,080	1,824			600	760	7,600	1,520
Licmophora abbreviata			240	20	80	80	200	9,200	320
Melosira monoliformis								1,600	

Location	Boughton River	Brudenell River	Covehead Bay	Darnley Basin	Murray River	Rustico Bay	Savage Harbour	St. Marys Bay	St. Peters Bay
Species	**6-Nov**	**6-Nov**	**4-Nov**	**21-Oct**	**5-Nov**	**27-Oct**	**4-Nov**	**6-Nov**	**4-Nov**
Mesodinium rubrum		320	480	60		80			
Protoperidinium bipes		160							
Navicula sp.	80								
Paralia marina	560	1,600					480		1,280
Pediastrum sp.?					80				
Pennate diatom	80	320		80		720	80	4,000	80
Pleurosigma / Gyrosigma		640		40	80	280		800	
Prorocentrum micans		160							
Prorocentrum minimum	400	640	160	40	80	50,286	40		
Prorocentrum spp.			80						
Protoperidinium spp.				20				200	
Pseudo-nitzschia sp. #1									
Pseudo-nitzschia sp. #2a	1,452,900	1,653,300	601,200	293,443	462,829	119,068	328,304	3,490,300	319,056
Pseudo-nitzschia sp. #2b									
Pseudo-nitzschia sp. #3	4,080	4,160	720	760	2,800	680	480	1,800	1,600
Pseudo-nitzschia sp. #4									
Pseudo-nitzschia sp. #5									480
Rhabdonema spp.		160							
Rhizosolenia hebetata var. *semispina*	80	320							
Rhizosolenia imbricata	320	480		100	400				80
Rhizosolenia sp. (fragment)								200	
Scrippsiella trochoidea				20	80		40	200	
Skeletonema costatum	618,460	72,576	263,872	4,026	940,290	33,600	7,700	37,960	35,424
Striatella unipunctata									80
Thalassionema nitzschioides	400	1,120							
Thalassiosira "tiny" sp.						160			
Thalassiosira spp.		480	400	40		80			
Unarmoured dinoflagellate			80			40			

Appendix F1. Phytoplankton cell numbers (cells L^{-1}), in Cardigan River, 2003.

Species	15-Sep	23-Sep	1-Oct	8-Oct	14-Oct	20-Oct	27-Oct	3-Nov	12-Nov	17-Nov	24-Nov	2-Dec
Amphidinium sphenoides		289										
Armoured dinoflagellate	3,757	2,601	1,445	578	1,156	5,202		2,890	2,119	385	2,023	867
Asterionellopsis glacialis							2,312	7,687	9,052	15,793	21,097	19,363
Centric diatom											1,156	
Cerataulina pelagica		7,225	578	4,335	9,248	5,202	16,646	8,670	13,289	10,015	10,982	4,913
Ceratium fusus				289								
Chaetoceros contortus	6,936	2,312	13,872	4,624	13,294	14,450	33,177	24,421		3,852		20,808
Chaetoceros danicus			2,312	1,156	578	1,156						
Chaetoceros debilis		867	2,601			1,734						
Chaetoceros didymus		4,335		867		1,734	6,936	3,468	1,348			
Chaetoceros didymus var *rotuberans*		2,601	1,734	578								
Chaetoceros lorenzianus			578	578		1,156	4,624					
Chaetoceros sp. A "filiform"	15,028	5,780	11,560	4,624	217,328	211,548	360,672	26,964		3,082	10,404	6,936
Chaetoceros spp.	109,531	69,938	12,716	4,624	22,889	43,350	48,552	14,161	8,860	13,867	29,478	7,803
Chaetoceros spp. (subgenus *Phaeoceros*)								578				
Chrysochromulina parkeae											289	289
Commation cryporinum							1,156					
Corethron criophilum			1,445	867		578						
Cyclotella spp.	3,179							578				
Cylindrotheca closterium	2,312	20,519	9,826	2,312	7,514	22,542	45,084	16,762	2,504	1,156	578	4,335
Dactyliosolen fragilissimus	1,156		289					9,930	1,348		289	3,179
Dictyocha fibula					578				193	770	289	
Dictyocha speculum						578			1,156			
Dinobryon spp.	6,069											
Dinophysis norvegica	289	289		578								
Ebria tripartita	289							289	193			
Eutreptia / Eutreptiella	578		1,734	289		1,156		289	193		289	
Guinardia delicatula	578			2,312		1,734		1,734	385	5,008	2,312	17,918
Guinardia striata									770			
Gyrodinium cf. *spirale*									578			
Gyrodinium spp.								289		385		1,156
Gyrosigma fasciola										385		

Species	15-Sep	23-Sep	1-Oct	8-Oct	14-Oct	20-Oct	27-Oct	3-Nov	12-Nov	17-Nov	24-Nov	2-Dec
Gyrosigma littorale	289			867								
Karenia mikimotoi	32,079	81,498	127,738	1,012,020	694,698	1,327,608	439,280	3,757	1,156			
Lennoxia sp.	15,317	23,120	8,670	3,179			2,312	578				
Leptocylindrus danicus	578						6,936	1,734	4,045	11,171	4,624	2,890
Leptocylindrus minimus											1,156	1,734
Licmophora abbreviata											578	
Mesodinium rubrum		289	1,734	289		578			770	1,541	578	1,734
Microcystis sp.		289										
Navicula sp.										385		
Odontella aurita										2,696		
Paralia marina		1,734	1,156									
Pennate diatom		1,445	289	578		578	4,624	1,445			289	
Phalacroma sp.	867						1,156					
Pleurosigma / Gyrosigma			289	867		578						
Pleurosigma angulatum	578	289						289	193			
Polykrikos cf. *kofoidii*		578		289	578	1,156						
Prorocentrum micans (Bérard)	289		289					289				
Prorocentrum minimum			289					578	193			
Prorocentrum spp.									193			
Protoperidinium spp.				289		578						
Pseudo-nitzschia americana	289	289	289									
Pseudo-nitzschia sp. #1		578				6,358	25,432	15,317	4,045	5,008	4,046	867
Pseudo-nitzschia sp. #2a												
Pseudo-nitzschia sp. #2b												
Pseudo-nitzschia sp. #3	6,358	5,491	578	2,023		5,202	19,652	12,427	5,971	2,696	5,780	
Pseudo-nitzschia sp. #4												
Pseudo-nitzschia sp. #5												
Rhizosolenia hebetata var. *hebetata*												
Rhizosolenia hebetata var. *semispina*		289	1,734	578	578	1,156		867	2,696	1,156		578
Rhizosolenia imbricata		289		289		578			770	770		578
Rhizosolenia pungens				289				2,312	385			
Rhizosolenia spp.					578	1,156	1,156			770	289	
Scrippsiella spp.		1,445	1,445				1,156					
Scrippsiella trochoidea				867								

Species	15-Sep	23-Sep	1-Oct	8-Oct	14-Oct	20-Oct	27-Oct	3-Nov	12-Nov	17-Nov	24-Nov	2-Dec
Skeletonema costatum	1,160,647	1,897,120	2,943,375	2,621,895	1,837,000	3,001,826	7,615,150	2,701,225	2,529,589	3,590,488	2,400,723	1,576,495
Striatella unipunctata												289
Thalassionema nitzschioides	10,693	867	867	578	1,156	2,890	23,120	23,554	41,461	36,209	56,933	136,986
Thalassiosira nordenskioeldii	289										4,913	9,248
Thalassiosira spp.	1,156	8,843	7,803			1,156	20,808	3,757	1,926			
Unarmoured dinoflagellate	1,734	1,156	5,491	2,312	5,202		3,468	289	963	385	289	2,890

Appendix F2. Phytoplankton cell numbers (cells L^{-1}), in Tracadie Bay, 2003.

Species	11-Sep	16-Sep	25-Sep	30-Sep	6-Oct	22-Oct	29-Oct	5-Nov	10-Nov	19-Nov	26-Nov	1-Dec
Armoured dinoflagellate	770	1,156	578	1,120	320		20	80		40	40	40
Asterionellopsis glacialis				160							80	
Attheya decora			289									
Cerataulina pelagica	8,051		289	800	2,240	1,552	20	40				
Chaetoceros contortus	7,196	29,305	20,230	10,240	3,200	1,280	100	1,440				
Chaetoceros debilis	28,071	135,541	9,826	48,640	6,400							
Chaetoceros radicans		1,156										
Chaetoceros socialis	2,311	34,680		7,040	7,696	960						
Chaetoceros sp. (3-5's)			225,420									
Chaetoceros sp. A "filiform"	7,165	5,202	29,478	7,680	12,560	3,864		1,000	400			
Chaetoceros spp.	6,240	40,460	14,450	57,600	11,704	5,312	200	240	1,400	360	560	
Chaetoceros spp. (subgenus *Phaeoceros*)				640								
Chaetoceros subtilis								120				
Chaetoceros teres				160								
Chrosochromulina parkeae								120			200	
Coscinodiscus spp.											40	40
Cylindrotheca closterium	193	289	1,156	1,520	240	240	140	40		40		
Cylindrotheca gracilis								40				
Dactyliosolen fragilissimus	247,876	4,335	867	3,520	4,896	320						
Dictyocha speculum				80								
Dinobryon spp.	1,348	8,670		800	2,880	920	100					
Ebria tripartita	578	289	289	80	160	160						
Eutreptia / Eutreptiella	27,734	1,445	289	320	720	1,320		80	40	120		
Guinardia delicatula	3,467		578	4,640	4,080	360	744	320	320			
Gymnodinium splendens					80							
Gyrodinium spp.						120	20	80	80	40		
Gyrosigma fasciola									40			
Gyrosigma tenuissimum				80			20					
Heterocapsa sp.		289		240	80							
Karenia mikimotoi	193											
Lennoxia sp.				80				40				
Leptocylindrus danicus	8,860	10,982	1,445	1,200	960		20					
Leptocylindrus minimus				1,440	560		200					

Species	11-Sep	16-Sep	25-Sep	30-Sep	6-Oct	22-Oct	29-Oct	5-Nov	10-Nov	19-Nov	26-Nov	1-Dec
Licmophora abbreviata				160	80		80	1,040	160	520	240	400
Mesodinium rubrum				240		80	80	80		80	200	
Microcystis sp.				80								
Odontella aurita										80	40	80
Paralia marina								440	120			240
Pennate diatom	385			80		40	20	120	80	40	40	80
Pleurosigma / Gyrosigma	193			80	400	280	20	80	40			
Prorocentrum micans	385			400	80							
Prorocentrum minimum	193	1,734		80	80	40						
Prorocentrum spp.	578			80	160				40			
Pseudo-nitzschia americana	578		289	1,200								
Pseudo-nitzschia sp. #1												
Pseudo-nitzschia sp. #2a			2,890	4,080	960	200	350	160	80			
Pseudo-nitzschia sp. #2b												
Pseudo-nitzschia sp. #3					320	480	580			280		
Pseudo-nitzschia sp. #4												
Pseudo-nitzschia sp. #5												
Rhizosolenia hebetata var. *hebetata*			289									
Rhizosolenia hebetata var. *semispina*				640	560	440	420	120	40			
Rhizosolenia imbricata		867		160	80		60	120	40			
Rhizosolenia pungens				560	80		180					
Rhizosolenia sp. (fragment)		289					20					
Scrippsiella spp.		289										
Skeletonema costatum	86,901	510,952	317,322	1,082,160	703,072	172,244	1,816	7,240	2,400	1,240	2,080	1,360
Thalassionema nitzschioides			1,156	1,200	1,384			80			800	
Thalassiosira spp.				1,760	2,344	1,200	1,260	520	120		160	

Appendix F3. Phytoplankton cell numbers (cells L^{-1}), New London Bay, 2003.

Species	15-Sep	22-Sep	30-Sep	6-Oct	14-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	2-Dec
Amphidinium carterae			193									
Amphidinium sphenoides			385									
Armoured dinoflagellate	400	1,156	2,504	4,913	1,012	800	80	40				
Asterionellopsis glacialis					434	400		440	160	37,018	19,376	44,537
Attheya decora			193									
Cerataulina pelagica			6,895	7,514	7,659	11,520	12,584			289		
Ceratium fusus	80											
Chaetoceros contortus	4,464	1,156	25,885	28,871	6,503	8,400	400	19,328	30,240	64,202	214,008	124,645
Chaetoceros convolutus var *trisetosa*							40					
Chaetoceros danicus							40					
Chaetoceros debilis			8,089				640	240		10,411		
Chaetoceros decipiens							480			1,157		
Chaetoceros didymus var *protuberans*				289								
Chaetoceros ingolfianus								1,600		2,603		
Chaetoceros laciniosus			1,156					80		1,446		
Chaetoceros lorenzianus			1,733			560	750	3,720	2,880	10,122	578	
Chaetoceros radicans										1,446		
Chaetoceros socialis			1,156			480						
Chaetoceros sp. A "filiform"		5,202	10,169	24,276	5,058	560				1,735	6,941	
Chaetoceros spp.	4,080	4,335	20,030	13,988	21,126	37,456	5,704	27,060	34,560	107,004	106,426	53,213
Chaetoceros spp. (subgenus *Phaeoceros*)			193									
Chaetoceros teres	480		963									
Chrosochromulina parkeae										289		578
Cylindrotheca closterium	1,040	2,890	12,712	4,913	3,035	1,360	240	680		868	289	
Cylindrotheca gracilis									80			
Dactyliosolen fragilissimus	240	2,023	2,889	578	5,058	3,800	3,050	480				578
Dictyocha speculum							80					
Dinobryon spp.	1,280		1,156		1,301	480						
Dinophysis acuminata		289						40			289	
Ebria tripartita		578			145							
Eutintinnus sp.			193									
Eutreptia / Eutreptiella		289	385	1,445	434	320		240	80			

Species	15-Sep	22-Sep	30-Sep	6-Oct	14-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	2-Dec
Grammatophora marina	80											
Guinardia delicatula	400		9,630	2,023	289	1,760	6,380	4,830	4,480	12,436	7,230	62,756
Gyrodinium spp.			385	1,156	2,601	1,760	560		480	1,157	578	289
Gyrosigma balticum	80	1,734	193	289	434		40					
Gyrosigma fasciola		578		289		80	40	360				
Gyrosigma littorale	400			867				240		289		
Heterocapsa sp.			1,541	1,734	145							
Heterocapsa triquetra		289										
Karenia mikimotoi	240		11,171	16,762	3,902	1,200	200	40				
Lennoxia sp.		867	385				640		80			578
Leptocylindrus danicus	560						360		240	1,157		289
Leptocylindrus minimus							680	240	240			
Licmophora abbreviata							80	360	80	578	578	868
Melosira spp.				867								
Mesodinium rubrum		1,156	385		145	1,120	80	40	160	1,157	1,735	2,892
Protoperidinium bipes							40					
Odontella aurita									160			
Paralia marina	80											1,157
Pennate diatom	2,320		193	578	578		240	1,040	480	868		289
Phalacroma sp.							40					
Pleurosigma / Gyrosigma	7,600	10,693	4,622	2,312	1,156	80		1,320	80	578		578
Pleurosigma angulatum	1,120	867	193	578	434		40	160				
Polykrikos cf. *kofoidii*				289								
Prorocentrum micans	80	867	1,733	578	145	160	40					
Prorocentrum minimum	160		578	1,445	1,445	160						289
Protoperidinium spp.		867		867	578		160	40	80			
Pseudo-nitzschia americana					289	320	240	40				
Pseudo-nitzschia sp. #1												
Pseudo-nitzschia sp. #2a		867	20,820	5,636	3,613	1,040	360	120	880	3,470		1,157
Pseudo-nitzschia sp. #2b												
Pseudo-nitzschia sp. #3			770	2,312	1,734	2,904	2,200	4,000	6,160	2,892	578	6,507
Pseudo-nitzschia sp. #4												
Pseudo-nitzschia sp. #5												
Pseudo-nitzschia sp. #6										578		
Rhabdonema spp.						80						
Rhizosolenia hebetata var. *semispina*	240	289	2,889	578	1,012	320	400	40	80			

Species	15-Sep	22-Sep	30-Sep	6-Oct	14-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	2-Dec
Rhizosolenia imbricata			385		289	240	480	40	320	289	578	289
Rhizosolenia pungens			1,733		145		40	120	80			
Rhizosolenia setigera				289								
Rhizosolenia sp. (fragment)	320		193	1,156		880	1,120	280				578
Scrippsiella spp.	160	289										
Scrippsiella trochoidea						80	640					
Skeletonema costatum	609,200	1,892,777	2,521,693	1,930,520	614,414	30,624	3,168	2,160	2,560	19,955	7,230	7,808
Striatella unipunctata							40					
Thalassionema nitzschioides	840	1,156	193				80				289	578
Thalassiosira auguste-lineata										3,181	289	2,892
Thalassiosira nordenskioeldii				578			240	1,120	4,240	477,469	115,102	464,455
Thalassiosira spp.			15,427	4,624		2,640	4,464	14,308		1,157		
Unarmoured dinoflagellate			385	289			40					

Appendix F4. Phytoplankton cell numbers (cells L^{-1}), Lennox Channel (Malpeque Bay), 2003.

Species	15-Sep	22-Sep	30-Sep	6-Oct	14-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	3-Dec
Amphidinium sp.		434										
Amphidinium sphenoides				1,156		145						
Armoured dinoflagellate	2,023	1,156	578	4,046	867	1,879	770	193	289	289		
Asterionellopsis glacialis					867		1,541	770				
Centric diatom												145
Cerataulina pelagica		145	578	8,092	156,060	290,040	270,218					
Chaetoceros contortus	8,092	10,404	40,460	4,624	14,306					3,468	41,616	6,815
Chaetoceros concavicornis / convolutus											2,312	
Chaetoceros danicus			1,156									
Chaetoceros debilis	578	5,058										
Chaetoceros decipiens											578	
Chaetoceros didymus		289	2,312									
Chaetoceros didymus var *protuberans*		2,023	4,046									
Chaetoceros lorenzianus											578	
Chaetoceros sp. A "filiform"	1,156	9,537	215,016	24,276	2,168	434					13,872	
Chaetoceros spp.	13,728	21,820	490,144	695,768	36,414	1,445	770	2,889	7,225	19,074	31,790	9,425
Chaetoceros spp. (subgenus *Phaeoceros*)				1,734								
Chaetoceros teres		145		1,734	2,168	434						
Chrosochromulina parkeae										289		
Cylindrotheca closterium	723	8,092	20,230	10,982	5,636	1,156		385	289		1,734	
Dactyliosolen fragilissimus					12,861	6,069	5,778	4,950	1,156	1,734	1,734	
Dinobryon spp.					2,746							
Dinophysis norvegica	145											
Dinophysis rotundata		145										
Dinophysis sp.	145											
Eutreptia / Eutreptiella		723	1,734	1,156	1,156	1,445	193	385				
Guinardia delicatula	578		1,734		1,734	2,168	6,548	103,195	200,855	323,102	700,536	602,910
Gyrodinium spp.	289	145			1,301	1,445	1,156		867		578	725
Gyrosigma tenuissimum						145						
Heterocapsa sp.					3,468	2,601						
Karenia mikimotoi	434	289	578	1,156	1,156	3,468	193					
Lennoxia sp.	723	1,590	4,046	578		145	1,156	385				

Species	15-Sep	22-Sep	30-Sep	6-Oct	14-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	3-Dec
Leptocylindrus danicus			2,312	1,156	723		3,274	7,126	867	5,780	17,918	4,785
Leptocylindrus minimus	578				2,890		2,889	4,622				2,465
Licmophora abbreviata			578					193		289	1,734	145
Mesodinium rubrum	145	434			578	1,734	770	385		1,156		290
Microcystis sp.	1,445	578	2,312		434							
Paralia marina		434	1,734			578	1,156				4,624	
Pennate diatom	145	289			578			770		289	2,312	
Pleurosigma / Gyrosigma								193			1,156	
Pleurosigma angulatum											578	
Polykrikos cf. *kofoidii*	145											
Prorocentrum micans		289										
Prorocentrum minimum	289						385		289			
Prorocentrum spp.					434		193		578			
Protoperidinium conicum				578	145							
Protoperidinium spp.		434		578	145	145	385	1,541	578			
Pseudo-nitzschia americana		2,876	5,780	3,468	578							
Pseudo-nitzschia sp. #1												
Pseudo-nitzschia sp. #2a	289		4,046	5,202	1,590	1,879	2,696	963	2,312	2,312	1,734	580
Pseudo-nitzschia sp. #2b												
Pseudo-nitzschia sp. #3		578			2,890	15,462	25,808	83,588	136,408	114,155	205,768	44,631
Pseudo-nitzschia sp. #4												
Pseudo-nitzschia sp. #5												
Pseudo-nitzschia sp. #6										1,156		
Rhizosolenia hebetata var. *semispina*	723		2,890	3,468	1,590	578	770	578	867			
Rhizosolenia imbricata	867	145	1,156	1,156	289	578	770	4,045	1,734	3,468	8,670	8,845
Rhizosolenia pungens					723							
Rhizosolenia spp.		145	578		867	434	963	8,474	4,624	5,491	8,670	15,660
Scrippsiella spp.		289			145	434						
Scrippsiella trochoidea	289	434			145	145			578			
Skeletonema costatum	1,513,016	1,903,802	2,201,059	906,813	67,915	31,646	1,926	5,778		2,312	4,624	1,160
Striatella unipunctata						145						
Thalassionema nitzschioides	2,457	4,480	4,046							289		
Thalassiosira nordenskioeldii											1,156	1,160
Thalassiosira spp.				1,156	2,312	2,457	14,445	20,993	867	1,734		
Unarmoured dinoflagellate		434	578							289		725

Appendix F5. Phytoplankton cell numbers (cells L^{-1}), other inlets, 2003.

Location	Boughton River	Brudenell River	Covehead Bay	Darnley Basin	March Water	Murray River	Rustico Bay	Savage Harbour	St. Marys Bay	St. Peters Bay
Species	**3-Nov**	**3-Nov**	**29-Oct**	**3-Nov**	**3-Nov**	**3-Nov**	**3-Nov**	**29-Oct**	**3-Nov**	**29-Oct**
Armoured dinoflagellate		756			80				2,023	40
Asterionellopsis glacialis	80	2,520				2,000			578	160
Attheya decora										40
Centric diatom		84				80				
Corataulina pelagica	1,280	4,788	160	100	40	400		120	2,601	40
Chaetoceros contortus	5,120	1,848				1,600	120		8,670	
Chaetoceros convolutus var. *trisetosa*					40					40
Chaetoceros danicus	160	84								
Chaetoceros decipiens					400					
Chaetoceros didymus	880	252				80				
Chaetoceros lorenzianus	160	4,704				1,680				120
Chaetoceros sp. A "filiform"	4,480	840	1,600			2,560		480	29,478	
Chaetoceros spp.	7,120	7,728	2,800	80	1,360	15,120	560	320	31,212	320
Cylindrotheca closterium	14,400	11,676	40	80		1,520	120	180	13,872	200
Dactyliosolen fragilissimus	2,800	7,392	440	220	1,440	2,080	200			320
Dictyocha fibula	240	672							289	
Dinobryon spp.								100		200
Dinophysis norvegica									289	
Ebria tripartita	320	504				80			289	
Eutreptia / Eutreptiella	80	924		80	280	160		120	1,156	
Guinardia delicatula	2,240	5,208	3,280	840	13,040	7,520	540	1,220	2,312	1,840
Gyrodinium spp.			40	20	240		20		1,445	40
Gyrosigma balticum				20			60			40
Gyrosigma fasciola	80			140			20			80
Gyrosigma littorale		84		20			100			
Gyrosigma tenuissimum	80	84						20		40
Karenia mikimotoi		2,184			240				60,112	
Lennoxia sp.					160		40			
Leptocylindrus danicus		168		180	2,600	640				
Leptocylindrus minimus		1,008		340	640		80			
Licmophora abbreviata	80			20			40	520		

Location	Boughton River	Brudenell River	Covehead Bay	Darnley Basin	March Water	Murray River	Rustico Bay	Savage Harbour	St. Marys Bay	St. Peters Bay
Species	**3-Nov**	**3-Nov**	**29-Oct**	**3-Nov**	**3-Nov**	**3-Nov**	**3-Nov**	**29-Oct**	**3-Nov**	**29-Oct**
Mesodinium rubrum	1,600	252	240	60				40	289	80
Navicula sp.	80	168								
Odontella aurita							40			
Paralia marina	960	672							1,156	
Pennate diatom		588	40	120			220			40
Phalacroma sp.		168							3,179	
Pleurosigma / Gyrosigma				20			40			40
Pleurosigma angulatum		84				80				80
Prorocentrum minimum		168								
Prorocentrum spp.		252								
Protoperidinium spp.				20	1,640					
Pseudo-nitzschia sp. #1										
Pseudo-nitzschia sp. #2a	10,560	5,040	840	60	760	3,200	100	280	2,601	800
Pseudo-nitzschia sp. #2b										
Pseudo-nitzschia sp. #3	12,080	9,996	2,880	320	18,840	19,120	80	1,340	6,069	3,160
Pseudo-nitzschia sp. #4										
Pseudo-nitzschia sp. #5										
Rhizosolenia hebetata var. *semispina*	2,240	3,024	320	20	480	800	60	700	2,023	1,120
Rhizosolenia imbricata		168	120	80	1,000	240		40		120
Rhizosolenia pungens	80	252	160		40	320	60	120		680
Rhizosolenia sp. (fragment)	160		40	80	520	160			289	280
Scrippsiella trochoidea				20	40					
Skeletonema costatum	2,922,480	2,176,608	34,040	560	1,160	579,760	200	2,180	3,087,387	640
Striatella unipunctata						80		40		80
Thalassionema nitzschioides	5,120	17,472		40		15,760	40		13,872	
Thalassiosira nordenskioeldii		924	800						1,156	
Thalassiosira spp.	320	3,108	2,640		2,280	1,680	140	240	2,890	280